HEATING MEDIA FOR PROCESSING FOODS IN FLEXIBLE PACKAGES PHASE II

by

I. J. Pflug

C. Borrero

Michigan State University
East Lansing, Michigan

Contract No. DA-19-129-AMC-145(N)

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HEAT MEDIA FOR PROCESSING FOODS IN FLEXIBLE PACKAGES
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FOREWORD

This contract was funded under Task 02, Project 1M643324D587, 64133241, and was transferred as of 1 July 1965 to Project 1M624101D552, 62141011, Task 02 - Design of Flexible Packaging Systems. The work on the project was conducted under the overall program to provide operational rations which satisfy the changing tactical and logistical requirements of the military. It is basic to the development of a family of lightweight, nonrigid packages for processed foods.

In the development of a nonrigid package for processed foods, consideration must be given to the selection of a processing media. Factors affecting the integrity of the package require a critical evaluation. Conventional methods of processing foods in rigid containers utilize heat from pure steam or water as the sterilizing medium. In the past, steam-air mixtures have been dubiously used. Because of the advantages steam-air offers in processing nonrigid packages, it was deemed worthy of further study. The information contained herein is the result of that effort.

This project was carried out in the Department of Food Science, College of Agriculture, Michigan State University. Dr. I. J. Pflug served as the Official Investigator and Mr. C. Borrero, Project Engineer. The cooperation of Wyeth Laboratories, Mason, Michigan; the Cranberry Products Company, Eagle River, Wisconsin; and all those persons in these companies and at Michigan State University who contributed to the project effort is gratefully acknowledged.

Project Officer for the U. S. Army Natick Laboratories was Mr. Joseph W. Szczeblowski and the Alternate Project Officer was Mr. Gerald L. Schulz, both of the Packaging Division, General Equipment and Packaging Laboratory.

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EDWARD A. NEBESKY, Ph.D.
Acting Director
General Equipment and Packaging Laboratory

</div>

APPROVED:

DALE H. SIELING, Ph.D.
Scientific Director

W. M. MANTZ
Brigadier General, USA
Commanding

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ABSTRACT

The objective of this study was to evaluate and compare steam, steam-air and water heating media for processing flexible packages and to develop suitable procedures for using these heating media in commercial processing equipment. A multipoint temperature recording device which measured the temperature of the heating medium and in the container at various locations was used to evaluate temperature gradients and heating rates for the vertical and horizontal retort and for the steam-air pasteurizer. The temperature distribution pattern and the rate of heating of water in 303x406 cans were determined for 100% steam, 90% steam-10% air and 75% steam-25% air mixtures, and water in a commercial vertical and horizontal retort and for a steam-air mixture in an atmospheric pasteurizer. Steam-air and water were evaluated at air flow rates in the range of 10-30 cfm. Steam and steam-air were evaluated using natural and mechanical circulation. The performance of the 3 heating media were studied in the vertical retort using both a cross and a circular spreader system. Satisfactory control procedures for processing flexible packages in the 3 heating media were developed for both horizontal and vertical commercial retorts. The horizontal retort was found to be a more effective configuration for processing using steam-air mixtures.

Summary and Conclusions

The behavior of 100% steam, 90% steam-10% air, 75% steam-25% air, and water in commercial, vertical and horizontal retorts using several air flow rates was studied by determining the temperature distribution pattern throughout the retort and heating rate of containers located at several points in the retort. In addition, steam-air mixtures were studied in a commercial pasteurizer. The results of these studies led to the following conclusions:

1. All three heating media will produce predictable reproducible results. Since the heat process is based on the heating characteristics of the food product in the retort under actual processing conditions, the heat process will vary with the physical system and the heating medium used.

2. There is a heating medium flow pattern in the retort that has a major effect on retort operation. The type of spreader and air flow rate affect the the heating medium gas flow rate, the relative rate of heating of the fastest and slowest heating container, and the location of the fastest and slowest heating container.

3. The retort loading pattern must permit flow of the heating medium in the vertical direction. This is important in flexible package processing where racks must be used; a slotted rack must be used that will not only permit but encourage flow of the heating medium in the vertical direction. This requirement is most critical for water but applies to both 100% steam and steam-air mixtures.

4. Temperature controls for all three heating media should be of the proportional mode to maintain the designed process temperature with minimum fluctuation. For steam-air, the control system must include a proportional pressure control system to operate the dump valve. Steam-air and water processes require an air metering device.

5. One hundred per cent steam is the simplest and most effective heating medium to use; water is next in simplicity with steam-air being the most complex. Undoubtedly, the commercial operator can do more things wrong using 100% steam and not get into trouble than with water or steam-air, and he probably can do more things wrong using water and not get into trouble than with steam-air. Under ideal conditions, however, all perform satisfactorily.

6. In water cooks, an air flow rate of 15 cfm through the steam spreader should be used. Air flows at the 15 cfm rate should be used not only during the come-up-time but also during the cook period. Provision must be made to allow water to circulate in a predetermined vertical flow pattern; solid horizontal plates that form impediments to vertical flow will create cold pockets. The suggested water flow pattern is up the outside of the baskets and down through the stack of product which can be effected by using a circular or fish-tail spreader.

7. In steam-air mixtures $T \geq 212°F$ the air should be added when the retort reaches process temperature. The air concentration in steam-air mixtures should be the minimum that will provide adequate container protection. For most food products the air concentration need not exceed 10%, with an air flow rate of 20 cfm.

8. The distance from the steam and air inlet to the top of the stack of cans is important in obtaining rapid uniform temperature in steam-air mixtures. The fastest equilibration was found in the steam-air pasteurizer, where this distance is a minimum; the horizontal retort had a relatively short height, therefore, uniform temperatures were established rapidly; the multi-crate vertical retort, which had the greatest container stack height required the longest time to reach equilibrium temperature.

9. The load of product to be processed in the retort and the heating characteristics of the product affect the performance of the retort.

10. The continuous steam-air pasteurizer is an effective device for processing high acid foods.

11. Steam-air mixtures and water processes may be used effectively for processing flexible packages in systems where there is positive flow of the heating medium. When processing flexible packages, temperature gradients will be smaller due to the smaller heat load and improved heating medium flow provided by the vertical slots in the pouch racks.

12. The procedures and equipment modifications stated in the body of this report may be used effectively to process flexible packages.

13. The small thickness of flexible packages, about 0.75 in., compared to that of a can provides for faster heating rates for the pouches thus higher quality food products may be obtained.

2. Introduction

2A. Objectives

In this project a vertical retort, a horizontal retort, and a continuous atmospheric pasteurizer were studied to determine the effect of heating medium on several processing parameters; the specific objectives of the project were:

1. To determine the temperature distribution pattern in a commercial, vertical and horizontal retort and in a continuous, atmospheric pressure, steam-air pasteurizer.

2. To determine the probable effect of temperature variations in the processing equipment on the lethality received by the product in the container.

3. Make an engineering analysis of the system.

4. Relate the results using the commercial equipment with the results obtained in the laboratory study in Phase I.

5. Interpret the results in terms of processing foods in flexible packages.

6. Make recommendations regarding the use of equipment and heating media for processing food in flexible packages.

The industrial revolution, the forerunner of our present science revolution, brought with it, most of our noteworthy industrial advances including canning. These industrial advances were invented and developed by practical people who were primarily interested in how to accomplish an objective rather than why the objective could be accomplished. Canning was invented and developed by practitioners; the canning industry as we know it today, evolved from the canning art. In some areas, the canning industry has developed into a complicated science; for example, the manufacture of metal and glass containers and closure systems. However, in the area of still-retort container processing, the design and operational procedures have changed very little in the last 50 years since the performance of the system was considered satisfactory.

A search of the literature dealing with the retort processing of food resulted in a large quantity of material describing retort manipulation but only a few reports where an actual attempt was made to evaluate the physical process. Excellent descriptions of retort operations are given by: Ball and Olson (1957), Bock (1965), NCA Bull. 26L (1962), NCA Bull. 30L (1963), Owens Illinois (1950), and Townsend et al. (1956).

Research dealing with the heat transfer process has been reported by Parcell (1930a,b), Hemler et al. (1952), Ball and Olson (1957), Pflug and Nicholas (1961), and Pflug and Blaisdell (1961). A great deal of work was done on retorting systems in the period between 1920 and 1930; Parcell's (1930a,b) study of several retorting systems is one of the most significant.

The use of steam-air mixtures is not new, Parcell (1930a) reported that it was possible to maintain a uniform temperature in a retort with steam-air mixtures after the retort had reached processing temperature. He observed that: the size of the load had an effect on the rate of come up to temperature, the steam and air should be mixed before being introduced into the retort, and circulation of the heating medium was important in producing uniform temperatures.

Considerable effort has been directed toward making the use of 100% steam foolproof. Hemler et al. (1952) reported on studies concerned primarily with the evaluation of air pockets in steam processes. They created an air pocket using a model system and established that containers in an air pocket receive less lethality than containers in 100% steam. This model is not applicable to steam-air processing. Ball and Olson (1957) evaluated several theoretical conditions where the presence of air in a retort could be encountered. Both Hemler et al. (1952) and Ball and Olson (1957) agree that in 100% steam processing venting of the retort is critical; venting must proceed in an effective manner in order to remove the air from the retort during the come up phase of the process.

Steam-air mixtures have been widely used in atmospheric pasteurizers since about 1945. Pflug and Nicholas (1961) studied the heating rates in glass containers as effected by the heating medium and product, particularly the comparison of steam-air mixtures with water bath, water spray, and 100% steam for model systems that heat by convection and conduction. They concluded that the efficiency of steam-air mixtures varied according to the percent of steam present. Pflug and Blaisdell (1961) studied the effect of the velocity of steam-air mixtures on the heating rate of glass containers and concluded that f decreased with increasing heating medium velocity and with increasing heating medium temperature over the range studied, 165 to 195°F. Pflug et al. (1963) studied the sterilization of food in flexible packages. They noted that the use of steam-air mixtures seemed to dispose of a number of disadvantages

associated with water cooks. Pflug (1964) developed procedures for processing foods in flexible packages in a laboratory retort and reported extensive heat penetration data for 100% steam, steam-air mixtures and water processes for food in both flexible packages and in 303x406 cans. This report covers Phase II of the latter work using commercial retorts. The overall reliability, reproducibility and safety of steam-air processing was compared to water and 100% steam. The second phase involved primarily verification of basic principles; therefore, cans rather than pouches were used for convenience. The results are applicable to pouches.

3A. Design of Vertical Retort Experiments

The vertical retort experiments were designed to meet the objectives outlined in Section 2B. The variables that had to be considered in the design of the experiments were: type of retort load, number of thermocouples in the retort, location of thermocouples in the retort, to have or not to have thermocouples in cans. If the decision was to have thermocouples in cans, how many; range of air flows in steam-air and water tests, steam-air mixture composition, number of different steam-air combinations to be tested and the values of those to be tested, number of basic retort modifications to be carried out such as different types of spreaders and circulation systems, number of tests to be run in each series, and the method of treating and reporting the data.

Obviously, the number of variables is sufficient that this project could have been continued for several decades. However, since it was a one-year project, it was necessary for us to decide specifically what were the important questions to be answered and then decide which tests would most likely provide the answers to the important questions.

Water in 303x406 metal cans was selected as the individual unit for the retort load because it was anticipated that the major problem in retort operation would occur during the period when the retort would be coming up to temperature and cans of water would provide the greatest heat sink during the initial portions of the cook. Following along with this reasoning, the retort was loaded to its maximum capacity to again provide maximum load.

The more temperatures that are measured in the retort, the more knowledge will be gained regarding behavior of the retort system. However, as the number of temperature measuring points increased, the requirements in the way of temperature measuring equipment and time for preparing, installing and checking temperature measuring equipment increased. It was decided that temperatures would be measured in four planes and at the center and periphery of each basket in each plane making a minimum total of eight points. In some tests the number of points was expanded to 12 where temperatures were measured at the center of the basket and then at two points on the periphery, one on the side of the dump valve outlet of the retort, and the other 180° away from the outlet.

The end result of our tests should provide information on the behavior of containers in the retort. It was concluded that the final effect could not be determined by simply measuring temperatures in the retort but that it was necessary to measure temperatures in cans in the retort. Since retort temperature and can temperature are, in the end, to be related, temperatures in the cans of water were measured at the locations where temperatures in the retort were measured.

The range of air flows used in the steam-air and water cooks was primarily based on judgment of practical levels that could be used. It was generally concluded that 30 cfm was about the maximum air flow from a practical standpoint; therefore this was the top range. On the low side, preliminary experiments, in general, indicated that flow rates of less than 10 cfm were of little value. Therefore, the general flow rates of 10, 20 and 30 cfm were used in the final experiments.

Two steam-air mixtures were selected for evaluation. A 90% steam-10% air mixture would represent the ideal steam-air processing level. However, it was felt that in some cases these results might be very close to the results of the 100% steam and therefore a lower steam-air ratio, 75% steam-25% air was evaluated to obtain an indication of what would happen at steam-air mixtures with lower steam fractions.

The number of basic retort modifications was limited to those that could be made in a practical preliminary testing period. Once a realistic and practical system of retort hook up was developed, this was used through the remainder of the experiment. Two different types of steam spreaders were used, a cross spreader and a new circular-type spreader. These two systems were used because of their considerably different general operation. A pump was used to circulate steam-air mixtures to determine if this was a feasible method to improve temperature distribution.

Preliminary tests were made in all cases. Usually the preliminary tests were made with thermocouples in the retort only (no thermocouples in cans). When the system had been fully checked out and sufficient preliminary data gathered, then final tests were conducted with thermocouples in the retort and in cans. Test runs were repeated until runs under commercial operation were obtained.

The method of treating the data was adjusted to fit the particular data. The fact that some of the semi-logarithmic heating plots were straight lines, some of them broke one time, some of them exhibited two breaks, and some were actually curves that became straight lines only in the last portion of heating, obviously dictated that presenting the results as f and j values would not make possible meaningful comparisons. It was decided that graphical presentation of the heat distribution data would be the most desirable method of presenting the data since this would allow the reader to actually see what happened at the different points as a function of time during the process. In thermal process calculation, the time required for the container to reach a high lethality value, a temperature near the heating medium temperature, is important. Therefore the time required for the containers at different points to reach different levels below heating medium temperature was tabulated so the reader can tell at a glance the general efficiency of the several different heating processes.

3B. Experimental

Equipment

The retort used in these studies was a three-crate, 3.5 ft. diameter x 7 ft. high, pressure retort fabricated in 1963 for use in high pressure canned food processing. The system was designed to be used with 110 psig steam pressure and 65 psig water pressure. The steam lines were nominal 1-1/2" steel pipe; the water lines were nominal 1-1/4" copper pipe and all drain lines were 2" steel pipe. The retort was controlled by a Foxboro Model 40 dual temperature and pressure recording controller. The temperature controller was actuated by a filled thermal type temperature sensing system. A cycle timer was used to time the cook and program the cooling cycle. A rotameter was located in the agitation air supply line. The initial retort piping system is shown diagramatically in Figure 3B1-1.

The retort control system was modified to improve the operation of the retort system. The modifications were as follows:

(1) A 3/4" proportional type air control valve was installed in the retort steam feed line in parallel with the existing 1-1/2" air control valve.

(2) A proportional type air controller using a thermocouple sensing element was installed to operate the 3/4" proportional control valve.

(3) An air flow meter with a hand valve for manual control of the air flow rate was installed in the air feed line (Brooks Rotameter Model No. 1100, range 5-100 cfm).

(4) A proportional type air controller with reset was installed to operate the dump valve. These modifications are shown diagramatically in Figure 3B1-2.

The 3/4" control valve in the steam circuit actuated by a proportional controller with a thermocouple sensing element was designed to limit the quantity of steam introduced into the retort and to remain in a throttled position during operation, thus eliminating the cycling of temperatures inside the retort during the process time. The need for a large quantity of steam at the start of heating necessitated using the 1-1/2" steam valve during the come up portion of the process, however, at the end of the come up cycle the 1-1/2" valve was closed with the processing temperature maintained by the proportional controller using the 3/4" proportional valve. This procedure proved satisfactory for attaining a temperature equilibrium in the retort. The use of a larger rotameter in the system, 5-100 cfm, made possible the use of steam-air mixtures with 20 and 30 cfm of air flow. The air passed directly from the rotameter to the retort. The air flow rate for each test condition was set manually with the hand valve.

The proportional pressure controller installed to throttle the dump valve controlling the pressure in the retort was installed because the studies of Phase I indicated that a continuous flow system was necessary for satisfactory operation using steam-air cooks if a uniform temperature was to be achieved throughout the retort. The modulation of the dump valve maintained the system under continuous flow conditions and eliminated pressure and corresponding temperature fluctuations, which in an on-off control system are due to the opening of the dump valve to release pressure with subsequent steam injection to maintain temperature.

The temperatures for the circular spreader tests and for the cross spreader tests, with and without recirculation, were measured using copper constantan thermocouples and a multi-channel one-minute cycle temperature recording potentiometer

system. The thermocouples were placed in four planes, two thermocouples per position in the cross spreader tests, three thermocouples per position in the circular spreader tests: a plain thermocouple was attached to the side of a can to measure heating media temperature, and a rod type thermocouple was placed in a can adjacent to the can with the plain thermocouple to measure the heating rate of a container filled with water. The thermocouple at the end of the rod was placed in the cold zone of the can to measure the temperature at the slowest heating point in the container. The construction and installation of the rod type thermocouples was described in the report of Phase I of this project. The distribution of thermocouples in the retort for the cross spreader tests is shown in Figure 3BI-3; one of the pair of thermocouples was placed in the middle of the basket and the other at the periphery of the retort basket for each of the four planes. Points 1 and 2 in the second plane were in the top layer of cans in the bottom basket; points 5 and 6 in the third plane were in the top layer of cans in the second basket; and points 7 and 8 in the fourth plane were in the top layer of the third or top basket. A thermocouple, point 9, was placed near the sensing element of the retort temperature controller.

The distribution of thermocouples throughout the retort for circular spreader tests is shown in Figure 3BI-4. Points 1, 2 and 3 in the first plane were in the first layer of cans in the bottom basket; points 4, 5 and 6 in the second plane were in the top layer of cans in the bottom basket; points 7, 8 and 9 in the third plane were in the top layer of cans in the second basket; and points 10, 11 and 12 in the fourth plane were in the top layer of cans in the third or top basket.

The gas pump used for heating medium recirculation was a Roots-Connersville 47XA rotary positive gas pump. The gas flow desired was controlled by varying the speed of the pump, the manufacturer provided charts relating gas flow, pump speed and pressure. The pump connected to the dump line at the top of the retort, the outlet of the pump was connected to the spreader pipe thus re-introducing the heating media into the retort through the spreader. This method of introducing the heating medium was designed to increase the mixing of the heating medium in the retort and to take advantage of the spreader as a means of distributing the heating medium. The retort operator controlled the pump by means of a magnetic on-off switch, the pump was started after making sure that there was no water entrained in the pump which would cause damage to the pump.

For all tests in the vertical retort, the retort load was 1400 303x406 cans of water, a convection heating product, creating the maximum load conditions in the retort.

Honeywell Proportional Temperature Controller

Foxboro Proportional Controller for Pump Valve

Foxboro M40 Dual Temperature-Pressure Controller

1-1/2"

2" Drain Pipe

3/4" Steam Valve

2" Bottom Drain

Steam Pipe 1-1/2"

Check Valve

Water Inlet 1-1/4"

Air Inlet 1/2"

Brooks Rotameter

Figure 381-2. Vertical retort piping diagram of modified control system.

Thermocouple

Lead view of thermocouple secured to can with tape

2'

3-1/2'

Cross section of the bottom crate showing the four rows of cans and thermocouple placement

Plan view of retort basket showing thermocouple placement

Cross section of retort showing the thermocouple placement

Figure 381-4. Diagram showing location of thermocouples for a vertical retort with the circular spreader.

2" Drain Pipe

2" Bottom Drain

1-1/2" Steam Pipe

Check Valve

Foxboro M40 Dual Temperature and Pressure Controller

Water Inlet 1-1/4"

1/2" Air Line

Rotameter

Figure 381-1. Vertical retort piping diagram of original control system.

Thermocouple

Lead wire of thermocouple secured to can with tape

2'

3-1/2'

Cross section of the bottom crate showing the four rows of cans and thermocouple placement

Plan view of retort basket showing thermocouple placement

Cross section of retort showing the thermocouple placement

Figure 381-3. Diagram showing location of thermocouples for a vertical retort with the cross spreader.

Experimental Procedure

The initial phase of the testing procedure was the assembling and testing of the control equipment, followed by careful loading of the retort. Retort baskets were hand stacked with the cans of water including the cans with thermocouples which were placed at the several selected locations. The filled retort baskets were placed into the retort; when all baskets were in place thermocouple leads were formed into a cable and brought out of the retort through the special stuffing box and connected to the potentiometer cable. The filled retort contained about 1,400 303x406 cans of water.

The measurement of temperature in the retort was made with a multi-channel potentiometer system with an accuracy of ±0.2°F or ±0.1°C. A stop watch was used to time the process. The process time usually was 25 min.; however, longer times were used with the slower heating processes so there was ample opportunity for the retort to equilibrate.

The initial temperature of the retort and contents was 80 ± 10°F; it was found in the preliminary tests that there were no appreciable differences in the come-up-time between the same retort load in this range of temperatures.

In steam-air tests, the addition of the air into the retort was studied in pre-liminary tests and it was found that introducing the air at the beginning of the process (steam on), or at 220°F, for a slow come up of the retort, increased the time necessary for the retort to reach equilibrium, when compared to tests where the air was introduced as soon as the first point in the retort reached process-ing temperature. The procedure used for all steam-air mixture tests was to introduce the air into the retort as soon as the first point in the retort reached processing temperature.

The cooling process was the same for all of the heating media; the retort was cooled until the containers reached 80±10°F. The fully loaded vertical retort described above was used to make replicate tests for the several air flow con-ditions for each of the three heating media. This experimental procedure was used for both spreader systems, with and without recirculation.

Retort operational procedure.

Procedure for 100% steam cooks.
1. Both of the temperature controllers were set for 240°F, the proportional type pressure controller was set for 13 psig to provide an overriding pressure on the containers during the cooling phase of the process and minimize pressure differentials across the can walls.

2. The retort was drained and the drain closed; the retort air supply line was closed and the retort then closed. The vent by-pass was opened.

3. The retort cycle was started by opening the 1-1/2" steam valve. The vent by-pass valve was maintained fully open for 4 min. or until the retort reached 220°F, whichever came last. Steam was then introduced through the 1-1/2" valve until the retort reached 240°F.

4. When the retort reached 240°F the cook cycle began; at this time the 3/4" steam valve was opened and the 1-1/2" steam valve closed during the remainder of the heating cycle. The temperature was controlled by the proportional type temperature controller with a thermocouple sensing element.

5. A few minutes before the end of the cook period the air was turned on to bring the pressure in the retort to 13 psig.

6. The cool cycle began by closing the steam valve, and opening the water valve to let water into the bottom of the retort.

The cooling operation, which was the same for all processes, consisted of introducing water into the bottom of the retort through a pipe opening and having the pressure controller maintain the pressure in the retort. As soon as the water level reached the level of the dump line, the water flowed continuously out of the retort. Throughout the whole cooling cycle, air was introduced through the steam spreader.

Procedure for steam-air mixtures.
1. Both temperature controllers were set for 240°F, the proportional pressure controller was set for 13 psig for 90% steam-10% air and 18 psig for 75% steam-25% air. The system was valved to introduce the air through the steam spreader. The air flow rate was controlled by a hand valve in the air supply line to the rotameter.

2. The retort was drained, the drain valve closed, the retort then closed. The vent by-pass valve was opened.

3. The retort cycle was started, the vent by-pass remained open for 4 min. or until the retort reached 220°F, whichever came last. The air valve was opened with the air introduced through the spreader and the rotameter set at 10, 20 or 30 cfm at the time the vent by-pass was closed.

4. When the retort reached 240°F, the cook cycle began, the 3/4" steam valve was opened and the 1-1/2" steam valve closed. The temperature in the retort during the heating cycle was controlled by the proportional controller with thermocouple sensing element.

5. The cooling cycle began by closing the steam valve and opening the water valve which introduced water through the bottom of the retort. Cooling proceeded as explained above.

Procedure for a water cook.
1. The retort was filled with water up to the water level mark; the retort was then closed.

2. Both temperature controllers were set for 240°F, the proportional pressure controller was set for 23 psig. The system was valved so that air was introduced through the steam spreader. The pressure controller maintained pressure by modulating the dump valve.

3. The retort cycle was started, the air valve was opened to introduce 10, 20 or 30 cfm of air, the 1-1/2" steam valve was opened.

4. When the retort reached 240°F, the cook cycle began; the 3/4" steam valve was opened and the 1-1/2" steam valve closed. The temperature during the remainder of the heating cycle was controlled by the proportional type controller with thermocouple sensing element.

5. At the end of the cook cycle the steam valve was closed and cooling water introduced through the pipe in the bottom of the retort. Cooling proceeded as described above.

<u>Procedure for the tests using the gas pump to recirculate steam and steam-air</u>
<u>mixtures.</u> The pump was operated at two speeds to give gas flow rates of 77 and
120 cfm. The procedure for operating the system with the pump was as follows:

1. The retort was brought up to temperature by the same procedure outlined above.
    When the retort reached 240°F and the 1-1/2" steam valve was closed with
    subsequent control by the 3/4" steam valve and pump was vented to remove all
    the water in the pump and turned b, hand to assure free movement.

2. The pump was then started, run for 30 seconds and then the air let into the
    retort at the desired flow rate.

3. At the end of the cook cycle the pump was turned off 30 seconds before steam
    off.

4. The cool cycle proceeded as described above for a regular steam or steam-air
    cook.

Analysis of Data

The data obtained from these tests were of two types. The temperature distri-
bution data obtained from the plain thermocouples, and the heating rate data
which were obtained from the rod-type thermocouples located in the containers
of water.

The temperature distribution data were plotted, temperature vs. time, on arithmetic
coordinate paper and analyzed by making visual comparisons among tests. A graph
was prepared for each test and contained the plot of each point in that test
identified by number with respect to its position in the retort; the points were
connected by a line giving an indication of the variation in temperature at each
point at all times during the test.

The charts are presented in the back of the respective section. In the preparation
of the report it was necessary to have several temperature distribution graphs
per page; from a comparison standpoint, it was necessary, for example, that the
three air flow rates for 90% steam-10% air and three air flow rates for water
cook be on the same page; the order for presenting the results will be as follows:
100% steam; 90% steam-10% air, 10, 20, 30 cfm of air flow; 75% steam-25% air, 20,
30 cfm of air flow; and water, 10, 20, 30 cfm of air flow.

The heating rate data were plotted on 3-cycle semi-log paper by the method of
Ball and Olson (1957). The analysis of these data by using f and j values was
not meaningful because the theoretical solution for the straight line curve
assumes that the container is heated in a heating medium of uniform temperature.
The f and j type of analysis may be used when a heat penetration test is made in
a laboratory set-up where 10 or 12 cans are heated and where the heat load and
retort come-up-time is very small. In our particular tests we have a retort
with a maximum load of cans, the come-up-time is quite large and there are
differences in the temperature come-up-time among points; therefore, the heating
rate curves for the containers have shapes other than a straight line.

The time required for the cans to reach $\Delta T = 3.6$ and $\Delta T = 1.8°F$ below heating
medium temperature is tabulated to indicate the relative rate of heating of cans
at different locations.

Heat Distribution Studies in a Vertical Retort

Heat distribution tests with the cross spreader.

The data obtained from the commercial vertical retort temperature distribution studies with the cross spreader were plotted temperature vs. time on a linear grid. These data were evaluated by making subjective comparisons between steam, steam with various concentrations of air, water, and comparisons of the effect of air flow rate on the heating properties of steam-air mixtures and water.

The results will be presented in the following order: 100% steam, 90% steam-10% air, 75% steam-25% air, and water with the steam-air and water tests presented in the order of increasing air flow.

100% steam. Tests made using 100% steam as the heating medium are shown in Fig. 3C1-1. The temperature profile during the come up of the retort was basically linear during the time the vent by-pass was open. The vent by-pass was open for 4 min., at which time the retort reached the processing temperature, 240°F. When the vent was closed, the temperature in the retort reached 243°F, however, the temperature of all points in the retort reached 240+1°F 2 min. later (Table 3C1-1). Point 1, in the bottom layer of cans, was at the highest temperature throughout the retort come-up-to-temperature phase. The maximum temperature difference between any two points in the retort during the come-up phase was 2°F.

Steam-air mixtures. Steam-air mixture tests were made with 90% steam-10% air and 75% steam-25% air for 10, 20, 30 cfm of air flow.

90% steam-10% air. The temperature distribution data for a 90% steam-10% air heating medium with 10 cfm of air flow are shown in Fig. 3C1-4. The come up of the retort was straight line; point 8 was first to reach processing temperature. The addition of the air to the retort caused a severe drop in temperature throughout the retort with the greatest temperature drop at point 6, 22°F and points 1 and 4, 18°F below processing temperature. The top plane in the retort, points 7 and 8 showed little or no drop in temperature during this period; point 9 at the sensing element had a maximum drop of 2°F, but recovered during the equilibration phase. The time for the slowest heating point to reach 240+2°F (Table 3C1-1) was 12 min. from the time the first point reached 240°F. The retort continued to approach equilibrium temperature until all points in the retort reached 240+1°F 13 min. after the first point reached processing temperature.

A representative test of 90% steam-10% air using 20 cfm of air is shown in Fig. 3C1-5 where the same general pattern described above for 10 cfm of air exists; however, the higher air flow rates cause some marked differences. The lowest temperatures during the equilibration phase was observed at point 6, however, point 4 suffered the greatest drop in temperature at the moment the air was added, 19°F. Points 3, 4 and 6 were slowest in reaching the equilibrium temperature; all points reached 240+2°F 10 min. after the first point reached 240°F,
    Point 9, the temperature at the sensing element in the retort, remained constant at the processing temperature throughout the test. The temperature of points 7 and 8 in the fourth plane were +1°F from processing temperature during the equilibration phase. The retort reached 240+1°F 12 min. after the end of the vent cycle (Table 3C1-1).

Tests with 90% steam-10% air using 30 cfm of air flow are presented in Fig. 3C1-6. This graph suggests that differences between 20 and 30 cfm air flow rates were

small. The largest temperature drop, 13°F, was observed for point 6. Points 3, 4 and 6 were at the lowest temperatures during the process. All the points in the retort reached 240±2°F 8 min. after the end of the vent cycle and reached 240±1°F 1 min. later (Table 3C1-1).

75% steam-25% air. The heating mixtures of 75% steam-25% air concentration were studied using 10, 20, and 30 cfm of air flow. In the preliminary tests 10 cfm of air flow were found to be of doubtful use because of the long time required to reach an equilibrium temperature. In addition, the 75% steam-25% air mixture with 10 cfm required 4 min. to achieve operating pressure. During this time it was not possible to ascertain the composition of the mixture because of constantly changing temperature and pressure conditions.

Representative temperature distribution data for 75% steam-25% air heating mixtures using 20 cfm of air flow are shown in Fig. 3C1-2. This chart indicated that the initial come up phase of the heating process was similar to the come up phase of the 90% steam-10% air tests; however, the introduction of air into the retort caused a large temperature drop at several points in the retort, and a longer time was required for temperature equilibrium. Points 1, 2, 4, 5, and 6 suffered the greatest temperature drop; the lowest temperature drop was at point 1, 29°F. However, 21 min., after the first point reached 240°F the temperature difference between the points in the first layer of cans in the retort and the rest of the retort was 5°F (Table 3C1-1). Points 7 and 8 in the top of the retort were not greatly influenced by the introduction of air; point 9, the temperature at the sensing element remained at processing temperature throughout the equilibration phase.

The graphical heat distribution data for 75% steam-25% air with an air flow rate of 30 cfm is shown in Fig. 3C1-3. Increasing the air flow from 20 to 30 cfm of air had the effect of decreasing the maximum temperature drop; the greater mixing effect of the 30 cfm appeared generally to change the heating pattern throughout the retort. An interesting result occurred in this test where the temperature in the top of the retort dropped during equilibrium in contrast to the other steam-air tests where the temperature did not drop. Point 6 was exposed to the lowest temperatures throughout the test and at the end of the test was 4°F below processing temperature, points 7 and 8 were initially 10-12°F below processing temperature and reached 240±2°F 12 min. after the first point reached 240°F (Table 3C1-1).

Water. The temperature variation of the retort in a water cook was studied using air flow rates of 10, 20 and 30 cfm.

A representative heat distribution graph for water with 10 cfm of agitation air flow is shown in Fig. 3C1-7. Tests using water cooks at 240°F with 10 cfm of air flow showed a more gradual come up than tests using steam; this was expected due to the greater heat capacity of water. The retort reached 240±1°F 7 min. after the first point reached 240°F. Point 1, in the bottom of the retort climbed 5°F above the process temperature at the beginning of the process but all points were at 240±1°F 17 min. after steam on (Table 3C1-1).

Water cook data for 20 cfm of air flow, Fig. 3C1-8, indicated that point 1 was the first point to arrive at 240°F. The retort temperature, point 9, at the sensing element in the bottom of the retort remained at 240±1°F during the equilibration phase of the process. All the points in the retort reached 240±2°F 4 min. after the first point in the retort reached 240°F and reached 240±1°F 2 min. later (Table 3C1-1).

Water cook tests using 30 cfm of air flow are shown in Fig. 3C1-9. Point 2 was the first point to reach processing temperature; the retort was at 240+2°F 2 min. after the first point reached process temperature and was at 240±1°F 2 min. later (Table 3C1-1). There was some temperature cycling during the equilibration phase, but this condition did not persist after 6 min.

Heat distribution tests with the circular spreader.

.Tests were carried out using the circular spreader using steam, steam with various concentrations of air, and water heating media. For each heating medium, studies were made to establish the effect of air velocity on the heating properties. The data will be reported as a representative temperature distribution graph for each heating condition. Temperatures were measured at 12 positions in the retort; at each position there was a rod type thermocouple and a plain thermocouple outside an adjacent can. The study undertaken covered the evaluation of: 100% steam; 90% steam-10% air, with 10, 20, 30 cfm of air flow; 75% steam-25% air with 20 and 30 cfm of air flow; and water cook with 10, 20 and 30 cfm of air flow. The evaluation of these media will be made in the above order.

100% steam. The temperature distribution results for tests using 100% steam at 240°F are shown in Fig. 3C1-10. The come-up-to-temperature of the retort was linear during the 4 min. time period the vent was open; the retort reached 240°F by the end of the vent period. Point 3 was first to reach 240°F. Points 10 and 12, in the top of the retort climbed 3°F above processing temperature but reached an equilibrium temperature of 240+1°F 4 min. after the first point reached retort temperature (Table 3C1-2). Point 5 in the middle of the second plane was slowest to reach retort temperature but was within 1°F 8 min. after steam was turned on. Initially there was some temperature cycling which was caused by the fast come up of the retort. The use of the 3/4" air operated valve to control the temperature during processing alleviated this condition.

Steam-air mixtures. Steam and air mixture studies were made using 90% steam-10% air and 75% steam-25% air for air flows of 10, 20 and 30 cfm. The air was introduced into the retort when the retort reached processing temperature. The test data will be described in the order of the increasing air velocity.

90% steam-10% air. A representative heat distribution graph for 90% steam-10% air for 10 cfm of air flow is shown in Fig. 3C1-13. The come up of the retort was similar to that for the 100% steam cook, but differences occurred after 4 min. when the vent was turned off and air introduced into the retort. The addition of air caused a temperature drop in the retort. Points 1 and 3 on the periphery of the first plane showed the greatest temperature drop, 5°F; points 1 and 6 recovered last. All points were within ±1°F of process temperature 8 min. after the first point reached 240°F (Table 3C1-2). There was a small drop in the overall temperature of the retort at approximately 8 min. from steam on, which was caused by cycling of the controller, but this condition was eliminated in the next four min. and an equilibrium temperature was reached 12 min. after steam on.

A representative graph of a 90% steam-10% air test using 20 cfm of air is illustrated in Fig. 3C1-14. The initial come up phase of the process was similar to the 10 cfm test, however, the temperature drop was greater at 20 cfm air flow. The maximum temperature drop for this condition was 9°F for point 5 and 8°F for point 6. The retort reached 240+1°F 6 min. after the first point reached process temperature (Table 3C1-2). There was some stratification of temperatures during the process with points 1, 4 and 5, 1°F above process temperature, and the rest of the points at process temperature.

Temperature distribution results for 90% steam-10% air tests using 30 cfm of air are shown in Fig. 3C1-15. This graph indicates that there were only small differences between 20 cfm and 30 cfm air flow rates. The maximum temperature drop occurred at point 12 which dropped 7°F from processing temperature when air was added but recovered after 8 min. In a manner similar to the 20 cfm air flow tests, points 1, 4 and 5 were at a higher temperature during part of the process; the stratification of temperatures is greater at 30 cfm air flow than at 20 cfm. All points were at 240±2°F 8 min. from the time the first point reached 240°F (Table 3C1-2).

75% steam-25% air. A representative temperature distribution chart of 75% steam-25% air for a 20 cfm air flow is shown in Fig. 3C1-11. The come up for this test was similar to that for the 90% steam-10% air; however, there was some peaking at the beginning of the process caused by the main steam valve being open too long. The addition of air into the retort caused point 5 to drop 8°F below control temperature. The maximum temperature drop was observed at points 1 and 5; points 1, 5 and 12 remained below retort temperature for the longest time; point 1 reached processing temperature 10 min. after air was introduced into the retort. Point 3 at the opposite side of the bottom plane, however, recovered quite rapidly and was at retort temperature after 3 min; this point was at the highest temperature in the retort during the process. The retort reached an equilibrium temperature of 240±2°F 15 min. after air was introduced and 240±1°F 1 min. later (Table 3C1-2). Equilibrium temperatures were maintained at all points during the rest of the process even though there was some temperature cycling caused by the lag in heating of the steam-air mixture.

The temperature distribution data for 75% steam-25% air using 30 cfm of air flow are portrayed in Fig. 3C1-12. The initial come up was the same as for 20 cfm; however, the addition of air to the retort caused a large temperature drop at points 4, 5 and 6 in the second plane of the retort. Points 1 and 3 remained at processing temperature during the equilibration phase of the process. The rest of the points reached 240±1°F 15 min. after the air was added to the retort (Table 3C1-2).

Water. The water cooks were studied at 240°F for the three air flow rates; 10, 20 and 30 cfm.

Temperature distribution data for a water cook with 10 cfm of agitation air are shown in Fig. 3C1-16. Tests made using water cooks at 240°F with 10 cfm of air flow showed a different type of a come up than that of the steam or steam-air cook; the first point to reach 240°F was point 3 with a maximum temperature difference between points of 6°F. The retort was at 240°F±1°F 3 min. after the first point reached process temperature (Table 3C1-2) and at 240±0.5°F 4 min. after the first point reached 240°F. There was some initial peaking of the retort with points 6 and 8 highest at 4°F above processing temperature, but this condition was alleviated after 1 min.

Temperature distribution data for a water cook with 20 cfm of agitated air are illustrated in Fig. 3C1-17. The retort come up for this air flow condition indicated that the temperature spread between points was not as great as that for a 10 cfm water cook; also the cycling of the retort was not as pronounced except for points 7 and 8 which cycle 2°F above process temperature with all other points at 240±0.5°F. The time for all other points to reach 240±0.5°F was 4 min. (Table 3C1-2).

Temperature distribution data for a water cook with 30 cfm of agitation air flow are shown in Fig. 3C1-18. The temperature come up of the tests using 30 cfm of air flow was similar to the 10 and 20 cfm flow conditions, however, the time for the first point to reach 240°F was 1 min. shorter for 30 cfm than for the two other air flow rates (Table 3C1-2). All points except 3 were at 240±1°F 3 min. after the first point reached 240°F (Table 3C1-2).

Heat distribution studies using the cross spreader with forced circulation of the heating medium.

The study of steam-air mixtures as a heating medium for food containers has revealed that a high rate of circulation of the heating medium is necessary to rapidly obtain uniform temperatures throughout the retort. To achieve a high circulation rate a gas blower was installed with the cross spreader in the vertical retort to create high circulation rates by forced gas flow. Tests were performed with the blower at two operating flow rates, 77 and 120 cfm. The results for the 77 cfm flow rate will be presented first, followed by the 120 cfm data.

100% steam. Temperature distribution data for 100% steam circulated at a rate of 77 cfm by the gas pump are graphically presented in Fig. 3C1-19. These results indicated all points in the retort were at 240±1°F 1 min. after the first point reached 240°F (Table 3C1-3). All points remained at 240±1°F during the process.

The temperature distribution pattern for 100% steam with 120 cfm externally circulated flow are illustrated in Fig. 3C1-25. All points in the retort were at 240±1°F one min. after the first point in the retort reached 240°F (Table 3C1-4); the retort remained at this equilibrium temperature throughout the remainder of the process.

90% steam-10% air. The temperature distribution pattern for 90% steam-10% air with 10 cfm of air flow recirculated at the rate of 77 cfm by the external pump is shown in Fig. 3C1-22. The temperature in the retort dropped when air was added; the largest temperature drop was 7°F, at point 6, in the third layer of cans in the retort. All points in the retort were at 240±2°F 3 min. after the first point reached 240°F (Table 3C1-3). The retort remained at 240±1°F throughout the remainder of the process.

Temperature distribution data for tests using 90% steam-10% air with 10 cfm of air and a recirculation rate of 120 cfm are shown in Fig. 3C1-28. The introduction of the air into the retort caused a temperature drop at point 6 of 8°F. All points in the retort with the exception of point 8 which was at 235°F for the first 8 min. of the equilibration phase were at 240±2°F 2 min. after the first point reached 240°F. All points in the retort were at 240±2°F 10 min. after the first point reached 240°F and at 240±1°F 3 min. later (Table 3C1-4).

The representative temperature distribution data for 90% steam-10% air at 240°F with 20 cfm of air flow and 77 cfm of circulation by the external gas pump are presented in Fig. 3C1-23. The addition of air to the retort in this case caused a severe temperature drop, 22°F, at points 5 and 7 in the third and fourth planes. Point 6 dropped 13°F, however, all points recovered quickly; a temperature of 240±2°F was reached by all points 4 min. after the first point reached retort temperature and 240±1°F 1 min. later (Table 3C1-3) except for point 7 which was 3°F below retort temperature 20 min. after steam on.

The graphical results of tests using 90% steam-10% air with 20 cfm of air flow and a forced recirculation rate of 120 cfm are presented in Fig. 3C1-29. The inlet of the air caused a temperature drop of 10°F to occur at point 8 in the top layer of cans. All points reached 240±2°F 13 min. after the first point reached 240°F and 240±1°F 2 min. later. The lowest temperature during equilibration occurred at points 4, 6 and 8 which were in the middle of the stack of cans at planes 2, 3 and 4.

The graphical results of temperature distribution data for 90% steam-10% air with 30 cfm of air flow and 77 cfm of gas recirculation are shown in Fig. 3C1-24. Point 9, the thermocouple at the sensing element in the retort, was first to reach 240°F. The addition of air to the retort caused a temperature drop of 10°F at point 6, in the third plane, and also affected points 1, 4 and 7. Point 9, the temperature at the sensing element remained at retort temperature throughout the test. All points in the retort were at 240±2°F 4 min. after the first point reached 240°F. Point 6 in the third plane fluctuated a maximum of 3°F after this time, but toward the end of the equilibration period reached 240±1°F. All points in the retort reached 240±1°F 11 min. after the first point reached processing temperature (Table 3C1-3).

The temperature distribution pattern for 90% steam-10% air with an air flow of 30 cfm and a gas pump circulation rate of 120 cfm are illustrated in Fig. 3C1-30. At 120 cfm equilibrium was reached more quickly for all points except 6 and 8 than for 77 cfm. The temperature difference between the points was decreased; all points except 6 and 8 were at 240±0.5°F 3 min. after the first point reached 240°F; an additional 9 min. was required for points 6 and 8 to rise to processing temperature (Table 3C1-9). Fig. 3C1-30 also indicates that the points in the middle of planes 3 and 4 were at lower temperatures than the rest of the points in the retort.

75% steam-25% air. The data for a representative test of 75% steam-25% air at 240°F with 20 cfm of air and with 77 cfm of forced recirculation by the gas pump are shown on Fig. 3C1-20. The first point to reach 240°F was point 9, the temperature at the sensing element. When the air was introduced into the retort 1 min. later there was a drop in temperature at points 1, 2, 3, 4, and 6. The largest temperature drop, 25°F, occurred at point 1, in the bottom plane of the retort. The points 1, 2, 3 and 4 in the first and second planes of the retort were at a lower temperature than the other points in the retort for 15 min. after the first point reached 240°F (Table 3C1-3). The temperature at these points, however, reached the processing temperature 16 min. after point 9 reached 240°F. Point 9, the temperature at the sensing element of the retort, was at 240±2°F during the equilibration phase of the process.

The temperature distribution data for 75% steam-25% air at 240°F with an air flow of 20 cfm and a recirculation rate of 120 cfm are shown in Fig. 3C1-26. The temperature profile for this test showed that the temperature drop, upon the addition of the air, for this heating medium, was largest at point 6, 5°F. During the test, however, point 8 dropped to 233°F and point 7 dropped to 236°F. The time for all points to reach 240±2°F was 16 min. after the first point reached 240°F and one additional minute to reach 240±1°F (Table 3C1-4).

The temperature distribution data for tests using 75% steam-25% air at 240°F with 30 cfm of air flow and a forced circulation rate of 77 cfm are illustrated in Fig. 3C1-21. The come up of this process was similar to 75% steam-25% air test using 20 cfm of air, however, the introduction of the air into the retort did not cause as large a drop in temperature. The maximum temperature drop occurred at point 6, 8°F, in the third plane. All points in the retort except 6 and 7 were at

240+1.5°F within 4 min. after the first point reached 240°F. Points 6 and 7 remained 1.5°F below retort temperature during the early part of the test. The final equilibrium condition was reached by all points 9 min. after the first point reached 240°F.

In Fig. 3C1-27 is shown a representative plot of the temperature distribution data for 75% steam-25% air at 240°F with 30 cfm of air flow and 120 cfm of forced re-circulation. Increasing the air flow rate from 20 to 30 cfm with forced recircula-tion of 120 cfm appears to cause larger fluctuations in temperature with the maxi-mum temperature drop at point 8, 10°F. The temperatures at points 6 and 8 are lower than the other points in the retort throughout the equilibration phase of the process. The retort approached 240+2°F 18 min. after the first point reached 240°F.

Figure 3C1-1 Temperature distribution in a vertical retort using 100% steam at 250°F with a cross spreader.

Figure 3C1-2 Temperature distribution in a vertical retort using 75% steam-25% air with 50 cfm of air at 260°F with a cross spreader.

Figure 3C1-3 Temperature distribution in a vertical retort using 75% steam-25% air with 30 cfm of air at 260°F with a cross spreader.

Figure 3CI-4 Temperature distribution in a vertical retort using 90% steam-10% air with 10 cfm of air at 240°F with a cross spreader.

Figure 3CI-5 Temperature distribution in a vertical retort using 90% steam-10% air with 20 cfm of air at 240°F with a cross spreader.

Figure 3CI-6 Temperature distribution in a vertical retort using 90% steam-10% air with 30 cfm of air at 240°F with a cross spreader.

Figure 3C1-7   Temperature distribution in a vertical retort using a water cock with 10 cfm of air at 200°F with a cross spreader.

Figure 3C1-8   Temperature distribution in a vertical retort using a water cock with 20 cfm of air at 200°F with a cross spreader.

Figure 3C1-9   Temperature distribution in a vertical retort using a water cock with 30 cfm of air at 240°F with a cross spreader.

Figure 3C1-10 Temperature distribution in a vertical retort using 100% steam at 240°F with the circular spreader.

TIME (min.)

Figure 3C1-11 Temperature distribution in a vertical retort using 25% steam-25% air with 20 cfm of air at 240°F with a circular spreader.

TIME (min.)

Figure 3C1-12 Temperature distribution in a vertical retort using 75% steam-25% air with 30 cfm of air at 240°F with a circular spreader.

TIME (min.)

Figure 3C1-13 Temperature distribution in a vertical retort using 90% steam-10% air with 10 cfm air at 240°F with a circular spreader.

Figure 3C1-14 Temperature distribution in a vertical retort using 90% steam-10% air with 20 cfm air at 240°F with a circular spreader.

Figure 3C1-15 Temperature distribution in a vertical retort using 90% steam-10% air with 30 cfm of air at 240°F with a circular spreader.

Figure 3C1-16 Temperature distribution in a vertical retort using a water cock with 10 cfm air at 250°F with a circular spreader.

Figure 3C1-17 Temperature distribution in a vertical retort using a water cock with 20 cfm air at 240°F with a circular spreader.

Figure 3C1-18 Temperature distribution in a vertical retort using a water cock with 30 cfm air flow at 250°F with a circular spreader.

Figure 3CI-19 Temperature distribution in a vertical retort using 10% steam at 260°F with a cross spreader; recirculation rate 77 cfm.

Figure 3CI-20 Temperature distribution in a vertical retort using 75% steam-25% air with 20 cfm of air at 210°F with a cross spreader; recirculation rate 77 cfm.

Figure 3CI-21 Temperature distribution in a vertical retort using 75% steam-25% air with 30 cfm of air at 210°F with a cross spreader; recirculation rate 77 cfm.

Figure 3C1-22 Temperature distribution in a vertical retort using 90% steam-10% air with 10 cfm of air at 240°F with a cross spreader; recirculation rate 77 cfm.

Figure 3C1-23 Temperature distribution in a vertical retort using 90% steam-10% air with 20 cfm of air at 240°F with a cross spreader; recirculation rate 77 cfm.

Figure 3C1-24 Temperature distribution in a vertical retort using 90% steam-10% air with 33 cfm of air at 240°F with a cross spreader; recirculation rate 77 cfm.

Figure 3C1-25 Temperature distribution in a vertical retort using 100% steam at 240°F with a cross spreader; recirculation rate 120 cfm.

Figure 3C1-26 Temperature distribution in a vertical retort using 75% steam-25% air with 20 cfm of air at 240°F with a cross spreader; recirculation rate 120 cfm.

Figure 3C1-27 Temperature distribution in a vertical retort using 75% steam-25% air with 30 cfm of air at 240°F with a cross spreader; recirculation rate 120 cfm.

TEMPERATURE (°F)

245

240

235

230

225

220

Figure 3C1-28. Temperature distribution in a vertical retort using
90% steam-10% air with 10 cfm air at 240°F with a
cross spreader; recirculation rate 120 cfm

4   6   8   10   12   14   16   18   20   22   24

T I M E (min.)

TEMPERATURE (°F)

245

240

235

230

225

220

Figure 3C1-29. Temperature distribution in a vertical retort using
90% steam-10% air with 20 cfm air at 240°F with a
cross spreader; recirculation rate 120 cfm

4   6   8   10   12   14   16   18   20   22   24

T I M E (min.)

TEMPERATURE (°F)

245

240

235

230

225

220

Figure 3C1-30. Temperature distribution in a vertical retort using
90% steam-10% air with 30 cfm of air at 240°F with
a cross spreader; recirculation rate 120 cfm.

4   6   8   10   12   14   16   18   20   22   24

T I M E (min.)

Table 3Cl-1. Time for all points in the vertical retort with the cross spreader to reach 240±5°, 240±2°, and 240±1°F.

	Time after the first point reached 240°F (min)			Time from start of heating (min)
	240±5°F	240±2°F	240±1°F	240±1°F
100% steam			2	6
90% steam-10% air				
10 cfm	10	12	13	17
20 cfm	3	10	12	16
30 cfm	4	8	9	13
240°F water cook				
10 cfm		6	7	17
20 cfm	1	5	6	19
30 cfm	1	2	4	15
				240±5°F
75% steam-25% air				
20 cfm	20			24
30 cfm	18			22

Table 3Cl-2. Time for all points in the vertical retort with the circular spreader to reach 240±5, 240±2, and 240±1°F.

	Time after the first point reached 240°F (min)			Time from start of heating (min)
	240±5°F	240±2°F	240±1°F	240±1°F
100% steam			1	5
90% steam-10% air				
10 cfm		6	7	11
20 cfm	4	4	6	10
30 cfm	2	6	11	15
75% steam-25% air				
20 cfm	8	11	12	16
30 cfm	10	15	15	19
240°F water cook				
10 cfm		2	3	13
20 cfm		1	3	13
30 cfm		1	2	10

Table 3Cl-3. Time for all points in the vertical retort with the cross spreader and 77 cfm of mechanical circulation to reach 240±5, 240±2, and 240±1°F.

	Time after the first point reached 240°F (min)			Time from start of heating (min)
	240±5°F	240±2°F	240±1°F	240±1°F
100% steam			1	5
90% steam-10% air				
10 cfm	2	3	9	14
20 cfm	7	4[a]	5[a]	9[a]
30 cfm	2	9	11	15
75% steam-25% air				
20 cfm	11	16	17	21
30 cfm	5	8	11	15

Table 3Cl-4. Time for all points in the vertical retort with the cross spreader and 120 cfm of mechanical circulation to reach 240±5, 240±2, and 240±1°F.

	Time after the first point reached 240°F (min)			Time from start of heating (min)
	240±5°F	240±2°F	240±1°F	240±1°F
100% steam			1	5
90% steam-10% air				
10 cfm	1	10	13	20
20 cfm	7	13	15	19
30 cfm	7	12	14	19
75% steam-25% air				
20 cfm	11	17		22
30 cfm	14	19+		25+

[a]All points except point 7 reached this temperature in this time.

Heating Rates of Containers in a Vertical Retort

The in-container heating rate studies for the vertical retort were made at the same time as temperature distribution tests. Temperatures were measured in eight 303x 406 cans of water using rod type thermocouples (Fig. 3B1-3). The temperature data were plotted on 3-cycle semi-logarithmic paper by the method of Ball and Olson (1957).

The usual and preferred method of analyzing the temperature-time data from containers of food is to plot the data and determine the f and j-values according to the procedures described by Ball and Olson (1957) after which the f and j-values for different tests can be compared. This procedure is usually used to evaluate the effect of container size or product in the container. In this project we were interested in determining the effect of temperature distribution in the retort by measuring the temperature in the can. In an ideal system, the temperature data of either a single container or several containers would lend itself to the heat penetration analysis of Ball and Olson's (1957), however, heating conditions in a fully loaded retort were much different than those encountered in an ideal system. In our situation the heating medium temperature was variable, the normally straight line heating graphs in many tests were curved; to compare the relative effectiveness of the several positions in the retort, the time for the containers to reach $\Delta T=3.6°F$ and $\Delta T=1.8°F$ was tabulated as a simplified and meaningful method for comparison of the relative effect of the heating medium.

The data in Tables 3C2-1, 3C2-2 and 3C2-3 make possible relative comparisons of the effectiveness of location and heating medium.

Heating rates of containers using the cross spreader.

100% steam. The heating rates of containers in 100% steam were quite uniform. There was a difference of 1 min. between the time required for the can in the center vs. the can in the periphery to reach $\Delta T=3.6°F$. Cans 5 and 6 and cans 7 and 8 in plane 4 were the fastest heating cans in the retort. The heating curves for the containers were essentially straight until $\Delta T=3.6°F$ was reached; then some of the heating curves broke. The range in times for the containers to reach $\Delta T=3.6°F$ was 7.0 to 9.0 min. and $\Delta T=1.8°F$ 9.5 to 12.0 min. (Table 3C2-1).

90% steam-10% air. The results of the heating rate studies of cans of water in 90% steam-10% air with 10 cfm of air flow indicated that the coldest zone in the retort was in the area of cans 4 and 6 in planes 2 and 3. In plane 1, can 2 at the center was colder than can 1; however, the temperature difference here was not as great as in planes 2 and 3. At the top of the retort in plane 4, cans 7 or 8 were at approximately the same temperature. In planes 2 and 3, 7 to 8 min. difference in time were required for the center of the basket to reach $\Delta T=1.8°F$ vs. the periphery of the basket. The heating curves for the cans in the center of the baskets, specifically cans 4 and 6, tended to break when the air was added to the system; however, the curves were essentially straight during the remainder of the heating cycle although there was a trend for the curves to break a second time in a ΔT of approximately 6°F. The times for the containers to reach $\Delta T=3.6°F$ ranged 9.0 to 22.5 min. and to reach $\Delta T=1.8°F$ 11.0 to 24.5 min. (Table 3C2-1).

Increasing the air flow rate from 10 to 20 cfm for a 90% steam-10% air mixture tended to produce more uniform temperatures throughout the retort, at least until a temperature $\Delta T=6°F$ was reached. The cans in plane 1 heated rather uniformly. In plane 2 the can at the center required a slightly longer time to reach the same temperature than the can at the periphery of the basket. Moreover, in planes

3 and 4, the can at the center of the basket required a considerably longer time to reach the same temperature than the can at the periphery of the basket. This difference in time to reach the same temperature was due to the fact that the curve of can 6 broke rather sharply at $\Delta T=6°F$ and the curve for can 8 broke at about $\Delta T=3.6°F$. In plane 3 there was approximately 12 min. difference in the time required for the can at the center of the retort vs. the can at the periphery of the retort to reach $\Delta T=1.8°F$. In plane 4 the difference in time to reach $\Delta T=1.8°F$ for can 7 vs. can 8 was 10 min. The times for the containers to reach $\Delta T=3.6°F$ ranged from 9.0 to 17.0 min. and for $\Delta T=1.8°F$ 10.0 to 25 min. (Table 3C2-1).

Increasing the air flow from 20 to 30 cfm for the 90% steam-10% air mixture decreased the temperature differences in planes 1 and 2 until, in general, the temperatures were uniform. The temperature of all eight cans in planes 1, 2, 3 and 4 reached $\Delta T=3.6°F$ quite rapidly; the difference in time was 4 min. between can 1 and can 4. The time for all cans to reach $\Delta T=1.8°F$ was much longer since the heating curve of can 6 broke at approximately $\Delta T=3.6°F$; can 6 required approximately 20 min. to reach $\Delta T=1.8°F$. The time for the containers to reach $\Delta T=3.6°F$ ranged from 9.0 to 17.0 min. and to reach $\Delta T=1.8°F$ 10.0 to 22.0 min. (Table 3C2-1).

75% steam-25% air. The tests made using 75% steam-25% air with 20 cfm of air flow were very different from the tests using 90% steam-10% air. The cans in planes 1, 2 and 3 had a very long come up time, although cans 5 and 6 in plane 3 heated faster than either of the cans in planes 1 or 2. The maximum heating time to $\Delta T=3.6°F$ was 28 min. for cans 1 and 2. Cans 7 and 8 in plane 4 had the shortest come up time. The times for the containers to reach $\Delta T=3.6°F$ ranged 11.0 to 28.0 min. and to reach $\Delta T=1.8°F$ 13.0 to 39.0 min. (Table 3C2-1).

Increasing the air flow rate from 20 to 30 cfm in a 75% steam-25% air mixture altered the heat distribution pattern. In the 30 cfm of air flow tests the hot zone in the retort was at planes 1 and 2, whereas in the 20 cfm air flow tests, the hot zone was at plane 4. The time for the four cans in planes 1 and 2 to arrive at $\Delta T=3.6°F$ was 9 min. Cans 5 and 6 in plane 3 were consistently at the lowest temperature. When all points in the retort except point 6 had reached processing temperature, point 6 was 3°F below processing temperature. Point 6 was approximately 4 ft. from the point of steam inlet. The times for all containers except can 6 to reach $\Delta T=3.6°F$ ranged 6.5 to 24.5 min. and to reach $\Delta T=1.8°F$ 8.5 to 28.0 min.

Water. The heating rates of the containers of water when heated in water were studied using 10, 20, and 30 cfm air flow rates. When an air flow rate of 10 cfm was used with a 240°F water cook, the temperatures were, in general, uniform in that can 1 reached $\Delta T=3.6°F$ in 16 min. and the slowest heating can was point 8 which reached $\Delta T=3.6°F$ in 19 min. The times to reach $\Delta T=1.8°F$ were 17 and 21 min., respectively, for the two points. In all cases, the containers at the periphery of the crates reached both $\Delta T=3.6$ and $\Delta T=1.8$ in a shorter period of time than the cans at the center of the crate. The time difference to reach $\Delta T=3.6°F$ varied from 0.5 min. in plane 3 to 2.0 min. in plane 1 and to reach $\Delta T=1.8°F$ from 1 min. in plane 2 to a maximum of 2.5 min. in plane 1. The time for the containers to reach $\Delta T=3.6°F$ ranged 16.0 to 19.0 min. and to reach $\Delta T=1.8°F$ 17.0 to 21.0 min. (Table 3C2-1).

Increasing the air flow rate from 10 to 20 cfm effectively reduced the time required for the containers to reach both $\Delta T=3.6°F$ and $\Delta T=1.8°F$. The time for the containers to reach $\Delta T=3.6°F$ ranged 14.0 to 15.5 min. and to reach $\Delta T=1.8°F$ 14.5 to 18.0 min. (Table 3C2-1).

The temperature distribution pattern for 30 cfm was similar to that for 20 cfm except that the time required for the temperature at all points to reach $\Delta T = 3.6°F$ and $\Delta T = 1.8°F$ was reduced and the range of times also reduced. Increasing the air flow rate from 20 to 30 cfm reduced the maximum time for $\Delta T = 3.6°F$ from 16 min. to 13 min. and the time to reach $\Delta T = 1.8°F$ from 18 min. to 14.5 min. for 20 and 30 cfm, respectively.

It was interesting to note that in the water cook processes studied, can 7 in the periphery heated faster than can 8 in the center of the top basket. This faster heating of can 7 was apparently caused by the increased flow through the annular space and would be most noticeable in the top layer of cans because the water will go up, turn the corner and then flow down; least flow could be in the center. The time for fastest vs. slowest container to reach $\Delta T = 3.6°F$ ranged 12.0 to 13.0 min. and to reach $\Delta T = 1.8°F$ 12.5 to 14.5 min. (Table 3C2-1).

Heating rates of containers using the circular spreader

The study of the heating rates of containers in a vertical retort with the circular spreader was made at the same time as the temperature distribution studies. The temperatures in 12 cans were measured using rod type thermocouples (Fig. 3B1-4). The retort loading pattern and the operational procedure for these tests was the same as that used for the cross spreader tests reported above.

100% steam. A summary of the heat penetration data for the containers of water in the vertical retort with the circular spreader using 100% steam as the heating medium is presented in Table 3C2-2. The heating pattern as shown by the heating rate data indicated that heating throughout the retort was quite uniform. The difference in time for the slowest and fastest heating container to reach $\Delta T = 3.6°F$ and $\Delta T = 1.8°F$ was 1 min. Can 1 on the periphery of the first plane was the fastest heating thermocouple can in the retort taking 6.5 min. to reach $\Delta T = 3.6°F$ and 7.5 min. to reach $\Delta T = 1.8°F$. The remainder of the cans in the retort reached $\Delta T = 3.6°F$ and $\Delta T = 1.8°F$ within 0.5 min. of each other. Fig. 3C2-1 is a semi-logarithmic plot of the heating rates of containers 1, 2, 4, 5, 6, 7, 10 and 11 for this heating medium. The time for the fastest vs. slowest container to reach $\Delta T = 3.6°F$ was 6.5 to 7.5 min. and to reach $\Delta T = 1.8°F$ 7.5 to 8.6 min., respectively.

90% steam-10% air. The results of the tests of cans of water in a 90% steam-10% air heating mixture, with an air flow rate of 10, 20 and 30 cfm are shown in Table 3C2-2. There was considerable uniformity in the heating with 90% steam-10% air at 10 cfm air flow rate due to the fact that all curves were similar in shape in that they all broke. The center of plane 1 was the coldest zone in the retort with the cans in plane 4 heating most rapidly. The times for the fastest vs. slowest cans to reach $\Delta T = 3.6$ and $1.8°F$ were 4.5 vs. 15 min. and 5.0 vs. 17.5 min., respectively (Table 3C2-2).

The general heating pattern for a 90% steam-10% air heating mixture was improved when the air flow was increased from 10 to 20 cfm. The major effect of the 20 cfm was to reduce the maximum times rather than reduce the minimum times. The relative times to reach $\Delta T = 3.6°F$ for the fastest vs. slowest heating cans were 4.5 vs. 10.8 min. and to reach $\Delta T = 1.8°F$ 7.0 vs. 13.5 min. (Table 3C2-2). Cans 1, 2 and 3 in plane 1 heated faster than the cans in planes 2 and 3, but not as fast as the cans in plane 4.

Heating characteristics for 20 cfm and 30 cfm of air flow for 90% steam-10% air were quite similar. The coldest can in the 30 cfm air flow tests was the can in the

top of the retort opposite the outlet to the dump valve. The overall flow pattern for the 30 cfm test was similar to that for 10 and 20 cfm; however, the cans in planes 1 and 2 heated faster. The heating curves for the cans in planes 3 and 4 broke resulting in a considerable difference between the time required for the cans in planes 1 and 2, about 7.7 and 9.4 min., respectively, and the time required for the cans in planes 3 and 4 approximately 12.5 min. to reach $\Delta T=1.8°F$. Figure 3C2-2 is a semi-logarithmic plot of the heating rates of containers 1, 2, 4, 5, 7, 8, 10 and 11 for this heating mixture. The overall range for the fastest and slowest can to reach $\Delta T=3.6°F$ was 6.5 vs. 9.5 min. and to reach $\Delta T=1.8°F$ 7.3 vs. 14.0 min. (Table 3C2-2).

75% steam-25% air. The heating pattern for the cans in the several positions in the retort for 75% steam-25% air with 20 cfm of air flow indicated that heating was not uniform. Cans 5 and 6 in plane 2 heated quite slowly, requiring 20 min. to reach $\Delta T=3.6°F$, and 26 min. to reach $\Delta T=1.8°F$. Plane 4 at the top of the retort contained the fastest heating cans; can 10, near the outlet to the dump valve and can 11 at the center of plane 4. However, can 12 at the periphery of the retort opposite the outlet to the dump valve required 17 min. to reach $\Delta T=3.6°F$ and 25 min. to reach $\Delta T=1.8°F$. The times for the fastest vs. slowest container to reach $\Delta T=3.6°F$ ranged from 5.0 to 20.0 min. and to reach $\Delta T=1.8°F$ from 6.0 to 26.0 min. (Table 3C2-2).

Increasing the air flow rate from 20 to 30 cfm for the 75% steam-25% air heating mixture changed the temperature distribution pattern in the retort substantially. The cans 4, 5, 6, 7, 8 and 9 in planes 2 and 3 heated more slowly than the cans in planes 1 or 4, with the exception of can 12 in plane 4. The heating rate of cans 1, 2 and 3 in plane 1 was much faster for the 30 cfm heating condition than for the 20 cfm tests. Nevertheless the fastest heating cans were located in the top plane of the retort. Can 10, located near the outlet to the dump valve reached temperature in the shortest time. The time for can 10 to reach $\Delta T=1.8°F$ was 4 min. compared to the 17.5 min. for can 11 in the center of plane 4. The times for the fastest vs. slowest heating containers to reach $\Delta T=3.6°F$ ranged from 4.0 to 19.0 min. (Table 3C2-2).

Water. The general heat flow pattern in the retort for the circular spreader appeared to be consistent for the 10, 20 and 30 cfm tests. In plane No. 1 containers 1 and 3 at the periphery heated more rapidly than container 2, at the center. However, in planes 2, 3 and 4, the general trend was for the containers at the periphery to heat more slowly or approximately equal to the containers at the center.

The tests carried out using a 240°F water cook with 10 cfm of air flow resulted in can 10 at the periphery of plane 4 to heat fastest with cans 2 and 4 in planes 1 and 2 with the longest heating times. The range of times required for the fastest and slowest cans to reach $\Delta T=3.6°F$ was 9.5 vs. 14.0 min., a range of 4.5 min., and to reach $\Delta T=1.8°F$ from 12.0 to 15.5 min., a range of 3.5 min. (Table 3C2-2).

Increasing the air flow rate from 10 to 20 cfm for the 240°F water cook resulted in more rapid heating and a somewhat smaller difference in time required for the fastest and slowest heating can to reach $\Delta T = 1.8$ and $3.6°F$. Can 10 in plane 4 heated fastest and can 2 in plane 1 was the slowest heating. The range of times for the fastest vs. slowest heating container to reach $\Delta T=3.6°F$ was 10.0 vs. 12.5 min., and 10.3 vs. 13.5 min. to reach $\Delta T=1.8°F$ (Table 3C2-2).

Increasing the air flow rate to 30 cfm further reduced the time required for the temperature to reach $\Delta T = 1.8$ and $3.6°F$. The increase in air flow to 30 cfm produced a more uniform temperature as evidenced by the fact that the range in times to reach $\Delta T = 3.6°F$ was from 10.0 to 11.5 min. and to reach $\Delta T = 1.8°F$ was 11.0 to 12.5 min. (Table 3C2-2). In both cases the range was 1.5 min. which was smaller than for either the 20 or 10 cfm flow rates. Increasing the air flow rate in the retort for a water cook from 20 to 30 cfm, while it reduced the time difference among cans, did not appreciably change the heating rate or the average time to reach $\Delta T = 1.8°F$ or $\Delta T = 3.6°F$. Figure 3C2-3 is a semi-logarithmic plot of the heating rates of containers 1, 2, 4, 5, 7, 8 and 10 and 11 for this heating medium.

Heating rates of containers using the cross spreader with recirculation by the gas pump.

The procedure for the tests using the gas pump was similar to the procedure described above for the tests with the cross spreader using natural circulation. The gas pump was turned on after the vent was closed for tests using 100% steam as the heating medium. In steam-air tests, the pump was also turned on after the vent was closed; however, in these tests, the air was added 30 seconds after the pump had been turned on. The heating rate tests using cans of water were made at the same time that the temperature distribution tests were made, in the same manner described above for the tests using the cross spreader without recirculation. The results will be described first for 77 cfm of recirculation and then for 120 cfm of recirculation for each heating medium studied.

100% steam. The tests to evaluate the relative heating rate of containers in the several parts of the retort when heated in 100% steam using the gas pump to recirculate the heating mixture at 77 cfm indicated that heating of the cans was quite uniform for all cans except can 2. · Can 2, in the middle of plane 1, reached $\Delta T = 3.6°F$ 10 min. after steam on, whereas the time for the remainder of the containers to reach $\Delta T = 3.6°F$ ranged from 7.5 to 8.0 min. In planes 2 and 3, the difference in the time required for cans 3 and 4 vs. cans 5 and 6 to reach $\Delta T = 3.6°F$ was 0.5 min.; however, in plane 1, the difference in time required for cans 1 and 2 to equal $\Delta T = 3.6°F$ was 2.5 min. Cans 7 and 8 at the top of the retort in plane 4 both required 8 min. to reach $\Delta T = 3.6°F$. The heating curves for all containers broke at about $\Delta T = 3.6°F$; therefore the time required to reach $\Delta T = 3.6°F$ was comparatively shorter than the time required to reach $\Delta T = 1.8°F$. The time for all containers to reach $\Delta T = 1.8°F$ ranged from 9.0 to 15.0 min. for the fastest and slowest heating cans, respectively (Table 3C2-3).

The tests using 100% steam and 120 cfm of recirculation showed approximately the same heating pattern as the tests using 77 cfm of recirculation. However, at the higher recirculation rate, the flow pattern as indicated by the relative time for containers in different parts of the retort to reach $\Delta T = 3.6°F$ was not as defined as for the 77 cfm tests. Can 2 in the center of plane 1 required 10.0 min. to reach $\Delta T = 3.6°F$ compared to 7.1 min. for can 1. In plane 3, cans 5 and 6 reached $\Delta T = 1.8°F$ at the same time; however, can 5 at the periphery of the basket reached $\Delta T = 3.6°F$ in a shorter time than can 6 in the center. The range of times for the cans to reach $\Delta T = 3.6°F$ was 7.0 to 10.0 min. and $\Delta T = 1.8°F$ from 8.5 to 16.0 min. respectively for the fastest and slowest heating cans (Table 3C2-4).

90% steam-10% air. The results of the heating rate tests of 303x406 cans of water heated in 90% steam-10% air with an air flow rate of 10, 20 and 30 cfm for recirculation rate of 77 and 120 cfm showed that as the air flow rate was increased

the heating pattern changed rather dramatically.

The heating rate data from the 90% steam-10% air tests using 10 cfm of air flow and a recirculation rate of 77 cfm, indicated that the heating pattern for this process was somewhat similar to the heating pattern for 100% steam. The slowest heating cans were: Can 1 at the periphery of plane 1; can 6 at the center of plane 3; and can 8 at the center of plane 4 which did not reach $\Delta T=1.8°F$ during the process; however, it reached $\Delta T=3.6°F$ after 8.0 min. The fastest heating can in the retort was can 7 at the periphery of plane 4 adjacent to the outlet of the retort or the inlet to the gas pump; can 7 reached $\Delta T=1.8°F$ after 6.0 min. The range in time for the fastest vs. the slowest heating container to reach $\Delta T=3.6°F$ was 5.5 vs. 9.0 min. (Table 3C2-3).

Increasing the rate of recirculation for the 90% steam-10% air heating medium with 10 cfm of air flow from 77 to 120 cfm altered the heating pattern appreciably. The fastest heating now occurred in planes 1 and 2 with cans 1, 2 and 3 requiring 8 min. and can 4 requiring 8.5 min. to reach $\Delta T=3.6°F$. The slowest heating cans in the retort were at planes 3 and 4, cans 5 and 6 requiring 13.0 min. and 12.0 min. respectively, and can 7 11.0 min. to reach $\Delta T=3.6°F$, whereas can 8 did not reach $\Delta T=3.6°F$ during the process. The heating curve for can 8 in the center of the top plane broke at $\Delta T=9°F$ and only reached $\Delta T=5°F$ at the end of the process. The time for all of the cans except can 8 to reach $\Delta T=3.6°F$ ranged from 8.0 to 13.0 min. and to reach $\Delta T=1.8°F$ 9.0 to 19.0 min. (Table 3C2-4).

The heating rate data from the tests using 90% steam-10% air with 20 cfm of air flow at a recirculation rate of 77 cfm indicated that in planes 2 and 3 the cans in the middle of the retort, cans 4 and 6, heated more slowly than the containers at the periphery of these planes. The cans in plane 2 heated more uniformly than those in plane 3; the time difference to reach $\Delta T=3.6°F$ was less in plane 2, 1 min., than in plane 3, 2.5 min. The fastest heating cans were located in planes 1 and 2, cans 1, 2, 3 and 4. In plane 4, can 7 required 20 min. to reach $\Delta T=3.6°F$ and never did reach $\Delta T=1.8°F$. In this particular case, can 8, at the center of the stack, was not evaluated due to thermocouple failure. The time for cans 1 through 7 to reach $\Delta T=3.6°F$ ranged from 7.0 to 20.0 min. and the time for cans 1 through 6 to reach $\Delta T=1.8°F$, 7.5 to 14.0 min. (Table 3C2-3).

Increasing the rate of recirculation for 90% steam-10% air with 20 cfm of air flow from 77 to 120 cfm caused the flow pattern to be more defined. The containers in the first two planes heated faster than those in the top two planes, with can 8 in the center of the top plane being the slowest heating can, and requiring 19.0 min. to reach $\Delta T=3.6°F$ and 24.0 min. to reach $\Delta T=1.8°F$. Can 7 at the periphery of plane 4 heated quite rapidly taking 11.5 min. to reach $\Delta T=3.6°F$ and 16.0 min. to reach $\Delta T=1.8°F$. The times for the fastest vs. slowest cans to reach $\Delta T=3.6°F$ ranged from 8.0 to 19.0 min., and to reach $\Delta T=1.8°F$ 9.0 to 24.0 min. respectively. (Table 3C2-4).

The results of the tests of heating rate of containers of water in 90% steam-10% air with 30 cfm of air flow and 77 cfm of recirculation indicated that the higher rate of air flow, 30 cfm, did not improve the behavior of the heating medium. The containers at the periphery of each plane heated faster than the containers in the center of the basket with the difference in the times required to reach $\Delta T=3.6°F$ increasing as the distance from the steam spreader increased. Cans 1, 2, 3 and 4 in planes 1 and 2 heated faster, 8.5 to 10.0 min. to reach $\Delta T=3.6°F$ than cans 5, 6, 7 and 8 in planes 3 and 4, 10.0 to 19.5 min. The times for

the fastest vs. the slowest cans in the retort to reach $\Delta T=3.6°F$ ranged from 8.0 to 19.5 min. and to reach $\Delta T=1.8°F$ 10.0 to 22.5 min. (Table 3C2-3).

The tests using 90% steam-10% air with 30 cfm of air flow and 120 cfm of recirculation did not substantially change the overall heating pattern and for this higher recirculation rate the flow pattern was not as well defined as for the 77 cfm tests. Can 1, the fastest heating can in the retort, was located at the periphery of plane 1, which was similar to the 77 cfm tests. In both cases the cans in the two bottom planes of the retort, planes 1 and 2, heated faster than the cans in the top half of the retort, planes 3 and 4. The heating rate of cans in the top of the retort indicated faster heating at the periphery than at the center of the basket and there were differences of 1.5 and 9.0 min. between cans in the center and the periphery of planes 3 and 4, respectively. Can 8 in the center of plane 4 did not reach $\Delta T=1.8°F$ during the process. The times for the fastest vs. slowest container in the retort to reach $\Delta T=3.6°F$ ranged from 9.0 to 21.0 min. and the time for cans 1 through 7 to reach $\Delta T=1.8°F$ ranged from 11.5 to 21.0 min. (Table 3C2-4).

75% steam-25% air. The results of the heating rate tests of 303x406 containers of water in 75% steam-25% air with 20 and 30 cfm of air flow with a recirculation rate of 77 and 120 cfm indicated that there was a marked difference in the heating pattern of 20 cfm of air flow as compared to 30 cfm of air flow in much the same way that differences existed between 20 and 30 cfm for the tests without recirculation.

The results of tests using 75% steam-25% air with 20 cfm air flow and 77 cfm of recirculation indicated that the cans at the periphery of each plane heated faster than the cans at the center of the plane. Comparison of the times required to reach $\Delta T=3.6°F$ indicated that there were differences of 6 min. in the heating rates of cans 1 and 2 and cans 3 and 4 in the periphery and center of planes 1 and 2. This difference was much larger in plane 3, 10 min. Can 8 at the center of plane 4 reached a temperature of 235°F. The time for cans 1 through 7 to reach $\Delta T=3.6°F$ ranged from 12.0 to 25.0 min. and to reach $\Delta T=1.8°F$ 16.0 to 32.0 min. (Table 3C2-3).

The tests where the recirculation rate was 120 cfm for 75% steam-25% air with 20 cfm and 120 cfm of recirculation showed that cans 1, 2, 3 and 4 in planes 1 and 2 were the fastest heating cans in the retort with small differences in the times to reach $\Delta T=3.6°F$. Cans 5 and 6 in plane 3 also heated in a similar manner; however, the curves broke and an additional 5 min. were required for these cans to reach $\Delta T=1.8°F$ than cans 1 and 2 in plane 1. The slowest heating cans were located in plane 4, cans 7 and 8. Can 7 at the periphery of the basket required 18.0 min. to reach $\Delta T=3.6°F$ and 27.0 min. to reach $\Delta T=1.8°F$. Can 8 reached a maximum temperature of 235°F during the process period. The times for the fastest and slowest heating cans for cans 1 through 7 to reach $\Delta T=3.6°F$ was from 9.0 to 18.0 min. and to reach $\Delta T=1.8°F$ from 9.0 to 27.0 min. (Table 3C2-4).

The heat penetration data from the tests of 75% steam-25% air with 30 cfm of air flow at 77 cfm of heating medium recirculation showed the fastest heating containers in the retort were cans 1 and 3 at the periphery of planes 1 and 2. These cans required 8.0 and 9.0 min. respectively to reach $\Delta T=3.6°F$. Can 2 at the center of plane 1 required 14.5 min. to reach $\Delta T=3.6°F$ and 21.0 min. to reach $\Delta T=1.8°F$; the heating curve for can 2 broke when air was added to the retort and also again when it reached $\Delta T=5°F$. Cans 6 and 8 in the middle of

planes 3 and 4 did not reach $\Delta T=3.6°F$ but at the end of the process reached $\Delta T=5°F$ and $\Delta T=7°F$ respectively. The heating curves for cans 5 and 7 broke twice--at air inlet and then again at $\Delta T=3.6°F$. The times for cans 1, 2, 3, 4, 5 and 7 to reach $\Delta T=3.6°F$ ranged from 8.0 to 14.5 min. and to reach $\Delta T=1.8°F$ from 9.5 to 21.0 min. (Table 3C2-3).

The heating rate tests for 75% steam-25% air with 30 cfm of air flow using 120 cfm of heating medium recirculation showed that for this case as for the 20 cfm tests with 120 cfm of recirculation, the cans in planes 1 and 2 heated faster than the other cans in the retort. The heating curves for cans 1, 2, 3 and 4 were essentially straight lines; however, for cans 5 and 6 in plane 3, the heating curves showed several breaks with can 5 heating more slowly than can 6. Can 7 in plane 4 at the periphery of the retort heated quite fast reaching $\Delta T=3.6°F$ in 7.0 min.; however, at this point the curve broke and 18.0 min. were required to reach $\Delta T=1.8°F$. Can 8 at the center of plane 4 reached a maximum temperature of 234°F during the process. There was no order to the rate of heating except to indicate better heating at the bottom two planes of the retort indicating that the height of the stack is an important consideration in designing steam-air processes. The time required for containers 1 through 7 to reach $\Delta T=3.6°F$ ranged from 7.0 to 24.5 min., viz., the time for the fastest and slowest heating container, and to reach $\Delta T=1.8°F$ required from 9.0 to 30.0 min. (Table 3C2-4).

(T-T), °C

TIME MIN

Figure 3C2-3. Heat penetration curves for 303 x 406 cans of water in a water cook at 240°F with 30 cfm of air flow in a vertical retort with the circular spreader.

(T-T), °C

TIME MIN

Figure 3C2-2. Heat penetration curves for 303 x 406 cans of water in 90% steam 10% air with 10 cfm of air flow in a vertical retort with the circular spreader at 240°F.

(T-T), °C

TIME MIN

Figure 3C2-1. Heat penetration curves for 303 x 406 cans of water in 100% steam in a vertical retort with the circular spreader at 240°F.

Table 3C2-1. Time for each container to reach 1.8 and 3.6°F below processing temperature in a vertical retort with the cross spreader

				Location					Range
	1	2	3	4	5	6	7	8	
100% steam									
ΔT=1.8	8.5	12.0	10.0	11.0	11.0	13.0	10.0	8.0	9.5-12.0
ΔT=3.6	7.5	9.0	7.0	8.0	8.0	8.0	7.0	7.0	7.0- 9.0
90% steam-10% air									
10 cfm									
ΔT=1.8	11.5	18.0	17.5	24.5	12.0	21.0	11.5	11.0	11.0-24.5
ΔT=3.6	9.5	17.0	14.0	22.5	9.5	18.5	9.0	8.5	9.0-22.5
20 cfm									
ΔT=1.8	10.0	12.0	15.0	17.0	13.5	25.0	12.0	22.0	10.0-25.0
ΔT=3.6	9.0	11.0	11.0	15.0	11.0	17.0	10.0	11.0	9.0-17.0
30 cfm									
ΔT=1.8	10.0	11.0	11.0	14.0	12.0	20.0	12.0	11.0	10.0-20.0
ΔT=3.6	9.0	11.0	11.0	13.0	11.0	12.0	10.0	9.0	9.0-13.0
75% steam-25% air									
20 cfm									
ΔT=1.8	32.0	32.0	30.0	39.0	24.0	19.0	14.0	13.0	13.0-39.0
ΔT=3.6	28.0	28.0	25.0	34.0	20.0	15.0	11.0	11.0	11.0-28.0
30 cfm									
ΔT=1.8	8.5	7.0	10.5	10.0	28.0	a/	23.0	24.0	8.5-28+
ΔT=3.6	8.0	6.5	9.0	9.0	24.5	a/	18.5	16.0	6.5-24+
240°F water cook									
10 cfm									
ΔT=1.8	17.0	19.5	18.0	19.0	20.0	20.5	19.0	21.0	17.0-21.0
ΔT=3.6	16.0	18.0	17.0	18.0	18.0	18.5	17.5	19.0	16.0-19.0
20 cfm									
ΔT=1.8	15.5	14.5	14.5	15.0	18.0	17.5	14.5	17.5	14.5-18.0
ΔT=3.6	14.0	14.0	14.0	14.5	16.0	15.0	14.0	15.5	14.0-15.5
30 cfm									
ΔT=1.8	13.0	12.5	13.0	13.0	14.0	13.5	14.0	14.5	12.5-14.5
ΔT=3.6	12.5	12.0	12.5	12.5	13.0	13.0	13.0	13.0	12.0-13.0

a/ Container did not reach temperature.

Table 3C2-2. Time for containers to reach 1.8 and 3.6°F below processing temperature in a vertical retort with the circular spreader

						Location							Range
	1	2	3	4	5	6	7	8	9	10	11	12	
100% steam													
ΔT=1.8	9.0	12.5	11.3	13.0	12.5	10.5	12.5	10.5	13.0	11.5	12.0	12.0	9.0-13.0
ΔT=3.6	7.3	8.7	9.5	8.5	8.3	8.3	8.0	8.3	7.5	8.3	8.0	8.0	7.3- 9.5
90% steam-10% air													
10 cfm													
ΔT=1.8	12.0	17.5	10.5	12.5	14.5	15.0	9.5	10.0	14.0	10.0	5.0	11.5	5.0-17.5
ΔT=3.6	10.0	15.0	9.0	8.0	10.5	10.5	7.5	7.5	9.5	6.5	4.5	8.0	4.5-15.0
20 cfm													
ΔT=1.8	7.8	9.0	8.0	11.5	11.0	10.8	12.0	11.0	11.8	7.0	7.5	13.5	7.0-13.5
ΔT=3.6	6.8	8.3	7.5	10.5	9.5	9.3	9.0	9.3	9.5	4.5	6.0	10.8	4.5-10.8
30 cfm													
ΔT=1.8	7.3	8.0	7.8	9.5	9.5	9.2	11.2	13.5	12.3	10.0	12.8	14.0	7.3-14.0
ΔT=3.6	6.5	7.3	6.5	8.0	8.0	7.8	8.8	9.5	8.8	8.0	9.5	12.5	6.5- 9.5
75% steam-25% air													
20 cfm													
ΔT=1.8	17.0	20.5	15.0	22.5	26.0	25.0	13.5	18.0	23.0	6.0	7.0	25.0	6.0-26.0
ΔT=3.6	14.0	18.0	12.5	15.0	20.0	20.0	10.0	13.0	17.0	5.0	6.0	17.0	5.0-20.0
30 cfm													
ΔT=1.8	8.0	11.0	10.0	20.5	18.0	18.0	a/	22.0	a/	4.0	17.5	a/	4.0-22+
ΔT=3.6	7.5	9.0	8.0	17.5	16.0	16.0	19.0	19.0	18.0	4.0	14.0	19.0	4.0-19.0
240°F water cook													
10 cfm													
ΔT=1.8	15.0	16.0	15.0	15.5	14.5	13.0	14.5	13.6	14.8	10.0	13.0	12.0	10.0-16.0
ΔT=3.6	13.8	14.0	13.5	14.0	12.5	11.5	13.0	12.0	13.3	9.5	11.5	11.5	9.5-14.0
20 cfm													
ΔT=1.8	13.0	13.5	12.8	12.8	12.3	11.8	12.5	10.5	13.0	10.3	10.8	13.0	10.3-13.5
ΔT=3.6	12.3	12.5	11.8	11.8	11.5	11.5	11.8	10.0	11.8	10.0	10.3	11.5	10.0-12.5
30 cfm													
ΔT=1.8	11.3	12.5	12.0	11.5	11.5	11.5	11.5	11.5	12.0	11.0	10.0	11.8	10.0-12.5
ΔT=3.6	10.5	11.5	11.0	10.5	10.5	10.3	11.0	10.5	10.8	10.0	9.8	10.5	10.0-11.5

a/ Container did not reach temperature.

Table 3C2-3. Time for containers to reach 1.8 and 3.6°F below processing temperature in a vertical retort using the cross spreader with 77 cfm of gas recirculation

	Location								Range
	1	2	3	4	5	6	7	8	
100% steam									
ΔT=1.8	9.0	15.0	10.0	13.0	14.0	14.0	13.0	15.0	9.0-15.0
ΔT=3.6	7.5	10.0	7.0	7.5	7.5	8.0	8.0	8.0	7.0-10.0
90% steam-10% air									
10 cfm									
ΔT=1.8	10.0	9.0	9.5	8.0	9.0	10.0	6.0	a)	6.0-10+
ΔT=3.6	9.0	7.0	7.0	7.0	7.0	8.5	5.5	8.0	5.5- 9.0
20 cfm									
ΔT=1.8	9.0	7.5	8.0	9.0	10.5	14.0	a)	b)	7.5-14+
ΔT=3.6	8.5	6.0	7.0	8.0	9.5	12.0	20.0	b)	7.0-20+
30 cfm									
ΔT=1.8	10.0	12.0	11.0	14.0	13.0	19.0	15.0	22.5	10.0-22.5
ΔT=3.6	8.5	9.0	8.0	10.0	10.0	14.0	12.0	19.5	8.0-19.5
75% steam-25% air									
20 cfm									
ΔT=1.8	19.0	26.0	16.0	23.0	31.0	32.0	22.0	a)	16.0-32+
ΔT=3.6	14.0	20.0	12.0	18.0	15.0	25.0	13.0	a)	12.0-25+
30 cfm									
ΔT=1.8	9.5	21.0	11.0	14.0	17.0	a)	20.0	a)	11.0-21+
ΔT=3.6	8.0	14.5	9.0	11.0	12.5	a)	12.5	a)	11.0-12+

a) Container did not reach temperature

b) Thermocouple failure

Table 3C2-4. Time for container to reach 1.8 and 3.6°F below processing temperature in a vertical retort using the cross spreader with 120 cfm of gas recirculation.

	Location								Range
	1	2	3	4	5	6	7	8	
100% steam									
$\Delta T=1.8$	8.5	15.0	10.0	12.0	14.0	14.0	13.0	16.0	8.5-16.0
$\Delta T=3.6$	7.1	10.0	7.0	7.0	9.0	8.0	7.5	8.0	7.0-10.0
90% steam-10% air									
10 cfm									
$\Delta T=1.8$	9.0	9.5	9.5	9.0	17.0	17.0	19.0	a)	9.0-19+
$\Delta T=3.6$	8.0	8.0	8.0	8.5	13.0	12.0	11.0	a)	8.0-13+
20 cfm									
$\Delta T=1.8$	9.0	14.5	14.5	19.0	21.0	22.0	16.0	24.0	9.0-24.0
$\Delta T=3.6$	8.0	11.0	11.0	14.0	16.0	17.5	11.5	19.0	8.0-19.0
30 cfm									
$\Delta T=1.8$	11.5	14.5	14.5	18.0	21.5	21.0	20.0	a)	11.5-21+
$\Delta T=3.6$	9.0	11.0	11.0	11.0	15.5	17.0	12.0	21.0	9.0-21.0
75% steam-25% air									
20 cfm									
$\Delta T=1.8$	10.0	10.0	9.0	9.0	17.0	15.0	27.0	a)	9.0-27+
$\Delta T=3.6$	9.0	9.0	8.0	8.5	13.0	11.0	18.0	a)	9.0-18+
30 cfm									
$\Delta T=1.8$	10.0	9.0	11.0	12.5	30.0	24.5	18.0	a)	9.0-30+
$\Delta T=3.6$	8.5	7.5	8.5	9.0	24.5	20.0	7.0	a)	7.0-24+

a) Container did not reach temperature.

Discussion of Results Obtained Using 100% Steam and Steam-Air Mixtures

Effect of air.

Heating conditions were evaluated for three levels of air: 0, 10 and 25%. The zero level of air is, of course 100% steam. The results of the temperature distribution studies for 100% steam in the vertical retort using the three steam conditions indicated that 100% steam required less time to reach an equilibrium processing temperature than the other heating media and produced more nearly uniform temperatures throughout the retort. The heating rate studies confirmed that this heating medium was the most uniform and produced container f-values that were smaller and had greater uniformity than the other heating media. This heating medium, 100% steam, is recommended for use whenever possible.

In the 100% steam tests the retort was vented during the retort-come-up time period. In the steam-air tests there were a number of optional operating procedures developed for retort come up; three were evaluated. The operational procedure selected was to bring the retort up to temperature using the same procedure as though 100% steam were to be the heating medium. When the retort reached processing temperature air was added to give the desired steam-air mixture.

In preliminary tests three different procedures for introducing the air into the retort were evaluated: 1) the air was started at the same time the steam was turned on; 2) air flow was started when the retort reached 220°F; and 3) air flow was started when the retort reached 240°F, the processing temperature. The first and second approaches were least satisfactory because the addition of air to the steam decreased the heat capacity of the heating mixture, and since the quantity of heat removed by the retort load remained constant there was a drop in retort temperature. The third approach was followed. In this method we still experience a temperature drop when air is added. The temperature drop is a function of the rate of heat removal.

In the ideal steam-air process for food in flexible packages we will heat with 100% steam until the product reaches process temperature and then add the air. However, this approach is not practical because the air pressure is needed to safeguard the package. If the packages are at processing temperature before the air is added and there is any noncondensable gas present, the internal pressure in the package will be greater than the retort pressure and pouch seals will be stressed and probably will fail. We believe that the procedure of adding the air when the retort reaches temperature is safe for processing flexible packages; at this time there is a 20 to 25°F ΔT between the temperature of the product in the package and the heating medium; therefore, the pressure in the pouch will be considerably below retort pressure.

If the performance of the retort is evaluated for the three air conditions 0, 10 and 25%, the results indicate that the addition of air to the steam heating system: increases retort come-up-time, decreases temperature uniformity, and increases the average f of containers of water in the retort.

When 0, 10 and 25% air are compared, there is a temperature drop throughout the retort when the air is added; the magnitude of this temperature drop was found to be largely a function of the percent air in the steam-air mixture, but it was also a function of the air flow rate. The temperature drop was larger for the 75% steam-25% air tests than for the 90% steam-10% air tests and the time for the heating mixture to equilibrate was longest with the largest amount of air. The amount of mixing required by the 75% steam-25% air was greater than for the 90% steam-10% air.

The study of the heating rates of containers in the laboratory retort in the Phase I studies indicated that there was some effect attributable to the percent air in the heating mixture on the f-value. The f-values found for 303 x 406 containers of water heated at 240°F were

	f (min)
100% steam	2.28
90% steam-10% air	2.63
75% steam-25% air	3.03

These results show an increase in the f-value with an increase in the percent air in the heating medium. In this study, where a maximum of 6 containers were processed in a single test we know that the heating medium was homogeneous and that uniform temperatures existed throughout the retort. The effects of the concentration of air in the heating medium on the heating rate of containers in the commercial retort were difficult to evaluate because of the size of the system and its deviation from ideal conditions. The evaluation of the relative merits of each system was made on the basis of: homogeneity of the heating medium, rapidity of come up and uniformity of heating of the containers. The results suggest that: 90% steam-10% air is similar to 100% steam, whereas 75% steam-25% air is a highly sensitive heating medium susceptible to large temperature drops, it is relatively difficult to equilibrate and produces measurably larger container f-values. The effect of the distribution system and air flow velocity will be discussed below.

Effect of heating medium velocity.

Effect of air flow rate. The temperature distribution tests using a 90% steam-10% air heating mixture with 10, 20 and 30 cfm of air flow in the vertical retort with a cross spreader indicated that an increase in the air flow rate: decreased the time required for the points in the retort to arrive at the equilibrium processing temperature; decreased the temperature drop when air was added to the retort, and increased the uniformity of heating in the retort by decreasing temperature differences between points during the process. The results of the heating rate of container tests showed: that as the air flow rates were increased there was greater uniformity of heating among containers; that flow of the heating medium was through the annular space between the retort basket and the retort wall, rather than through the stack of cans, with faster heating of the containers located at the periphery than those at the center of the basket; that there appeared to be stratification of the heating mixture at planes 3 and 4 since heating was more predictable and more homogeneous in planes 1 and 2; and that with the increase in the air flow rate, the magnitude of the slope of the container heating curve after the break (broken heating curves), was decreased as indicated by the decrease in the difference between the time to approach $\Delta T=3.6$ and 1.8°F. The breaks in the curves for cans 6 and 8 for the 20 and 30 cfm tests took place later than for 10 cfm of air; however, there were large differences in the time to reach $\Delta T=3.6$ and 1.8°F which apparently were due to the poor flow conditions at the center of the basket. Increasing the air flow rate decreased the time differences to reach $\Delta T=3.6$°F between the containers at the periphery and those in the center of the basket; this decrease was probably due to an increase in mixing.

The study of 90% steam-10% air heating mixtures in the vertical retort with the circular spreader for the three air flow rates showed that increasing the air flow rate from 10 to 20 cfm decreased the time to reach equilibrium temperature; however, there was a difference of 1°F between points 1, 4 and 5, and the rest of the points in the retort after equilibrium temperature was reached. The temperature drop at air inlet was not as large for the 10 cfm air flow test as for the 20 cfm test.

Increasing the air flow rate from 20 to 30 cfm made little difference in the time to approach equilibrium; however, in the 30 cfm case the retort equilibrated at 240±2°F. The temperature distribution charts suggest that there was no definite advantage in increasing the rate of air flow from 20 to 30 cfm and the increase in effectiveness was hardly significant between 10 and 20 cfm. The heat penetration data for 90% steam-10% air heating mixtures using the circular spreader indicated that the flow rate of air had a marked effect in the heating pattern in the retort as follows: for the 10 cfm tests the slowest heating region was in planes 1 and 2 with the top plane having the fastest heating cans. When the air flow rate was increased to 20 cfm the slowest heating zone was located at planes 2 and 3 with faster heating at planes 1 and 4. The 30 cfm tests caused a further rise of the cold zone to the top two planes in the retort, in this case planes 1 and 2 had the fastest heating containers. The increase in the air flow velocity substantially reduced the maximum time and the range in heating times for the containers to reach $\Delta T=3.6$ and $1.8°F$. The heating rate data suggest that increasing the air flow rate increases the uniformity of heating of the containers; this effect was quite noticeable when the air flow was increased from 10 to 20 cfm, but hardly noticeable when the air flow rate was increased from 20 to 30 cfm.

The study of the temperature distribution of 75% steam-25% air heating mixtures with 20 and 30 cfm of air in the vertical retort using the cross spreader indicated that when the air was added large temperature differences were created between the different points in the retort. These differences in temperature along with the slow equilibration times of the points in the retort make 75% steam-25% air a poor process compared to 90% steam-10% air or 100% steam. Increasing the air flow rate from 20 to 30 cfm decreased the maximum temperature drop from 30°F to 27°F, however, it did not substantially improve the uniformity of temperature or decrease the equilibration time. In a similar fashion to the 90% steam-10% air tests there was a marked shift in the hot and cold zones with change in air flow. At 20 cfm of air flow the cold zone was in planes 1, 2 and 3 and at 30 cfm the cold zone was in planes 3 and 4. This particular phenomenon was also substantiated by the heating rates of the containers which indicated the same heating pattern.

The temperature distribution tests of 75% steam-25% air for the vertical retort with the circular spreader using 20 and 30 cfm of air flow indicated marked differences between these two air flow rates. The increase in air flow rate from 20 to 30 cfm did not decrease the time to reach equilibrium temperature; it was found that the 30 cfm air flow rate test was not as uniform as the 20 cfm test since the 20 cfm test had greater uniformity of temperatures and a smaller temperature drop at air inlet, 8°F, compared to 24°F for 30 cfm of air. The heating rate tests of containers in 75% steam-25% air heating mixtures indicated that an increase in the air flow rate did not appreciably change the heating rates of the containers. At the 30 cfm air flow rate the containers in plane 1 heated faster than in the other 3 planes. The range of times for the containers to reach $\Delta T=3.6$ and $1.8°F$ was about the same for both air flow conditions. The container adjacent to the dump valve line inlet heated faster for the two air flow rates in 75% steam-25% air than for 100% steam. This was undoubtedly caused by the high rate of flow out the dump valve line under these conditions. The heating rates of the containers show large time differences between the containers to reach temperature. The logarithmic plots of the curves indicated a marked lag in the rate of heating caused by the introduction of the air into the retort. These two factors suggest that even for the circular spreader 75% steam-25% air is not a satisfactory heating medium for the air flow rates studied in the vertical retort. The data from the tests using 75% steam-25% air for 20 and 30 cfm in the vertical retort with the cross spreader indicate that for the conditions in our experiment this heating medium is too unpredictable to be of use in processing

because of the wide range of heating conditions encountered throughout the retort and the significant differences in heating rates of the containers.

In the preliminary studies it was observed that the presence of air in a still retort may cause cold zones in the retort if the gas in the retort became stagnant. The addition of air to the retort in an intermittent fashion that occurred when a large dump valve was operated by an on-off controller was found to aid in establishing these stratified conditions. When the control system was modified by modulating the dump valve with a proportional type pressure controller and air was metered into the retort continuously through a rotameter there was sufficient flow to prevent stratification and maintain a uniform temperature.

Increasing the rate of air flow to the retort in steam-air cooks changes the heat distribution pattern but does not always improve heating conditions. With 90% steam-10% air, a 20 cfm of air flow produced best results with the circular spreader but 30 cfm of air flow produced best results when the cross spreader was used. There was not a very large difference between the results in the circular spreader tests using 20 and 30 cfm.

The rate of air flow seems to have a direct effect on the flow pattern in the retort in that at high air flow rates the flow to the retort increases steam flow and since there must be continuous venting, improves circulation. It appears that very high air flow rates tend to direct flow from the steam and air inlet to the vent outlet and may not improve circulation throughout the retort.

Relationship of height of stack and air flow. The tests of 90% steam-10% air with 10, 20 and 30 cfm of air flow using the cross spreader indicated that as the air flow rate was increased, the cold zone in the retort tended to migrate upward; at 10 cfm the containers in planes 1, 2 and 3 heated much slower than containers in plane 4. When the air flow rate was increased from 10 to 20 cfm, the cans in plane 1 heated fastest, when the air flow rate was increased from 20 to 30 cfm the containers in planes 1 and 2 heated fastest and with relatively uniform heating. This effect was much more evident for the 75% steam-25% air tests where in the 20 cfm tests the slowest heating containers were in planes 1 and 2, but when the air flow rate was increased from 20 to 30 cfm the cold zone shifted and the containers in planes 1 and 2 heated uniformly and faster than the containers in the other zones of the retort.

The tests using the circular spreader also indicated that air flow rate and height of can stack had an effect on the temperature distribution in the retort. The heating rate tests for 90% steam-10% air with 10, 20 and 30 cfm of air showed in a manner similar to the cross spreader tests that an increase in the air velocity moved the cold zone from the bottom toward the top of the retort. In the 10 cfm tests the fastest heating containers were in planes 3 and 4; however, when the air flow rate was increased to 20 cfm the hot zone was located in planes 1 and 4, and a further increase in the air flow rate to 30 cfm caused the hot zone to be located at planes 1 and 2. The tests of 75% steam-25% air with 20 and 30 cfm of air showed the same effect, the fastest heating zone in the 20 cfm tests was located at plane 4, increasing the air flow rate from 20 to 30 cfm moved the hot zone from the top of the retort, plane 4, to the bottom, plane 1.

The results of the steam-air tests using 90% steam-10% air and 75% steam-25% air at 10, 20 and 30 cfm of air flow indicate that the height of the stack of cans is a critical consideration in design when a steam-air heating medium is used. The height of the stack and the rate of air flow appear to be interrelated since the cold zone in the retort migrated upward with increased air flow.

Mechanical.circulation. The use of a mechanical pump to circulate large volumes of
the gaseous heating medium was the third in a sequence of operations to increase the
efficiency of the heating medium by increasing velocity. Changing the air flow rate
and altering the spreader design from a cross to a circular spreader all have an
effect on the heating medium flow pattern. The mechanical circulation of the heating
medium was a normal next step in this development.

The mechanical gas pump was used to circulate the heating medium when 100% steam was
used to observe the effect of mechanical circulation even though we anticipated no
benefit. The results supported our prognosis since the results indicated that there
was little difference in the heating pattern between the tests with mechanical circula-
tion and those without mechanical circulation. In some respects, heating was poorer
in the tests when mechanical circulation was used compared to tests without mechanical
circulation of the steam. For example, temperature differences in the several parts
of the retort were 240±2°F with mechanical circulation compared to 240±0.5°F when there
was no mechanical circulation. The results of the heating-rate-of-containers study
showed that cans at the center of plane 1 did not heat as fast as cans in the other
locations. The explanation for this difference is that the high velocity steam
apparently bypasses the center of the bottom basket, but, because the basket and con-
tainers break up the steam flow, the containers located at the center of planes 2, 3
and 4 do not heat appreciably slower than the containers at the periphery of these
planes. In both the 77 and 120 cfm mechanical circulation tests, can 2 heated slower
than the other cans. The tests without mechanical circulation showed approximately
the same temperature distribution pattern; however, the heating rate data indicated
that more uniform heating was obtained in tests without mechanical circulation. The
results indicate that for 100% steam processing, the use of the mechanical circula-
tion system in this project did not improve the process.

The tests of 90% steam-10% air heating mixture with mechanical circulation and with
air flow rates of 10, 20 and 30 cfm, showed large differences in the temperature
profiles and heat penetration data between the various air flow rates and mechanical
circulation rates. In general, increasing the air flow rate for both mechanical
circulation rates did not improve the uniformity of the temperatures within the
retort, but rather caused greater temperature differences between the several points
in the retort. This effect was probably due to our imposing a circulation flow
pattern on the retort which was not complete in itself but at the same time destroyed
the natural flow pattern. In the mechanical circulation system, the flow of heating
medium occurred mainly from the steam spreader to the dump valve line inlet which
served as the inlet line to the mechanical pump. While we distributed the heating
mixture rather uniformly in the bottom of the retort, flow out of the top was at a
point which will have an effect on the overall flow pattern. From our results it was
obvious that the velocity must be uniform thoughout. Increasing the velocity in one
area will certainly improve conditions in this area but may make the total picture
much worse.

The 75% steam-25% air heating media were evaluated for two air flow and two mechanical
circulation rates. It is possible that mechanical circulation was a little more
beneficial in the 75% steam-25% air heating media tests than in the 90% steam-25% air
tests; however, the differences were small and in no case was there a clear cut re-
sult indicating that there was real benefit with mechanical circulation. In general,
the comments and discussions relating to the 90% steam-10% air steam-air mixture are
appropriate for 75% steam-25% air heating medium.

An evaluation of the overall effect of mechanical circulation of steam or steam-air

mixtures leads to the inevitable conclusion that under the conditions studied mechanical circulation did not improve the uniformity of the temperatures or the heating rate of containers in the retort, but to the contrary, in most cases apparently increased temperature differences.

The tests using the circular spreader when compared to the cross spreader tests with and without mechanical circulation, showed that internal circulation can be more effective than mechanical circulation. The temperature profile for the circular spreader tests using 90% steam-10% air with 10, 20 and 30 cfm of air flow showed that there was a greater temperature uniformity in the 10 cfm tests than in the 20 and 30 cfm tests. The temperature drop upon air inlet was very small. The heating rate of containers data for the circular spreader showed that increasing the air flow rate had a marked effect on decreasing the time for the containers to reach $\Delta T=3.6$ of $1.8°F$.

At this point, there is no question that the rate of flow of the heating medium is important in establishing temperature uniformity, but we have shown that in our mechanical circulation system there was no direct correlation between a high mechanical circulation rate and an increase in temperature uniformity. These tests do show that there are ways of improving the uniformity of a process by initiating and maintaining optimum air flow rates.

The experimental data further suggest that in processing containers in steam-air mixtures using mechanical heating medium circulation the retort study used in this project was not the ultimate in design. By looking at the temperature profile and heating rate data, we may observe that the flow of the heating medium is up in the annular area between the retort and the sides of the basket. In the case where the cross spreader was used with mechanical circulation, it was apparent that the heating medium bypassed the center of the top plane and sometimes the containers in plane 3, as it flowed out the vent line to the mechanical pump inlet. We feel that this effect could be reduced by eliminating the free flow area and forcing the heating mixture to flow through the stack of containers. This type of arrangement would eliminate the differences in the heating rates between the containers at the periphery of the retort and those at the center and would aid in establishing more uniform temperatures because of greater mixing due to the forced convection condition. At the same time a re-design of the steam inlet and steam outlet systems should be considered. From our heating rate data, we observed that the containers at the center of plane 1, can 2, did not heat as rapidly as the can at the periphery of plane 1. A steam spreader which will distribute steam and air uniformly throughout the bottom area of the retort will aid in establishing homogeneous heating conditions. At the same time, if mechanical circulation is to be used, a system should be designed so that the heating medium is taken off the entire top area of the retort rather than at one point in the top of the retort. It is not feasible, at this time, to bring in the heating mixture at the top of the retort, take it out from the bottom and circulate it back in the top due to condensate and pumping problems. However in the top and out the bottom is the normal flow pattern in the retort and if a sufficient volume of heating medium could be circulated and a system could be devised for circulating from top to bottom during the heating phase, many temperature distribution problems would be eliminated. Needless to say, the suggested systems would have to be evaluated experimentally before final recommendations could be made.

In conclusion, we have evaluated and compared the rate of circulation of the steam and steam-air heating media and found that the design of a mechanical circulating system will not be an improvement in obtaining a uniform heat process temperature over the circular spreader system with the circulation promoted by air flow.

Modifications for a future study of mechanical circulation have been suggested, but they will require further experimental evaluation.

Effect of flow pattern of the cross spreader vs. the circular spreader.

The flow pattern produced by a steam distribution system in a retort is dependent on the location of the device in the retort and the gas flow rate. In this study two basic types of spreaders were used: The cross spreader, which is the standard device recommended for use in vertical retorts and a circular type steam spreader which was developed as part of this project. The cross spreader consists of four arms that have the outlet steam holes on one side, the four arms are arranged so that the steam is discharged in two alternate quadrants of the retort to create a swirling, sweeping action to help move the air out of the retort at the beginning of the cycle to assure the development of a homogeneous heating medium as soon as possible after the start of the process. The circular spreader was designed to discharge the steam vertically in the annulus between the retort crate and the outside wall of the retort, aiming the flow upward toward the top of the retort. The cross spreader and the circular spreader were tested using the same heating media and same type of retort load to determine if the type of steam spreader had an effect on the heat distribution pattern in the retort.

The tests using the cross spreader indicated that the flow of steam or steam-air mixture moved up from the spreader hitting the floor of the bottom crate of cans where the flow was broken up with the major part of the gas moving toward the outside, then up through the annular area between the retort crate and the wall. This effect may be easily seen from the tables of heating rate of container data where the container in the center of the basket did not heat as rapidly as the container at the periphery of the basket.

In the circular spreader tests, the flow was designed to go up the annular area and down through the stack of cans. This result was achieved in that the containers in the middle of the crate heated about as fast or faster than the containers at the periphery of the retort crate.

The fastest heating containers in the cross spreader tests were at the periphery of plane 1. The can at this location was subject to the largest gas flow rate due to the general flow of the heating medium rounding the corner of the basket to flow up the annular area on its way up to the top of the retort and out the dump valve line. In the circular spreader tests, the fastest heating container in the retort was can 10 at the periphery of plane 4, which was adjacent to the dump valve line inlet. The f-values for this container for some of the higher air flow rates were quite small; in fact, even smaller than the f-values for the same container in 100% steam.

The difference in the temperature distribution for the two spreader systems using 90% steam-10% air with 10 cfm of air flow was as follows: when the circular spreader was used 11 min were required for the retort to reach $240 \pm 1°F$ while 17 min were required when the cross spreader was used. The test with the circular spreader had smaller temperature differences just after the air was added, 5°F for the circular spreader compared to 22°F for the cross spreader. The temperature differences during the process between points in the retort were smaller with the circular spreader than with the cross spreader.

The heating rate tests for 90% steam-10% air with 10 cfm of air flow showed a marked difference in the f-value of containers at the various locations for both systems. When the cross spreader was used, the containers at the periphery of the basket

heated much faster than the containers in the center of the basket; for the circular spreader tests the containers in the center of the basket heated as fast or faster than those in the periphery except in plane 1 where can 2 was the slowest heating can in the retort. The heating rate of the cans was more uniform in the circular spreader tests than in the cross spreader tests. The differences in time to reach $\Delta T=3.6$ and $1.8°F$ between containers in the same plane were less for the circular spreader tests than for the cross spreader tests and the range of times for the fastest vs. the slowest heating containers to reach $\Delta T=3.6$ and $1.8°F$ were less for the tests with the circular spreader than for the tests using the cross spreader.

The heat distribution data obtained with the two spreader systems for 90% steam-10% air with 20 cfm of air flow resulted in smaller temperature fluctuations with the circular spreader at air inlet, $9°F$, than with the cross spreader, $14°F$. The time to reach $240\pm1°F$ was less for the circular spreader, 11 min after steam on, than for the cross spreader, 17 min. The temperature difference between points during the process was less for the circular spreader $\pm1°F$ than for the cross spreader $\pm1.5°F$. The heating of the containers was more uniform for the circular spreader range of 4.5 to 10.5 min to reach $\Delta T=3.6°F$ and 7.0 to 13.5 min to reach $\Delta T=1.8°F$ as compared to a range of 9.0 to 17.0 min to reach $\Delta T=3.6°F$ and 10.0 to 25.0 min to reach $\Delta T=1.8°F$ for the cross spreader tests.

The results of temperature distribution tests using 90% steam-10% air and 30 cfm of air flow for the two steam spreaders indicated that the temperature drop at the time of air inlet was greater for the cross spreader, $13°F$, than for the circular spreader, $8°F$. The time to reach $240\pm2°F$ was shorter when the circular spreader was used; 10 min from steam on, than for the cross spreader, 12 min. The temperature fluctuation between points during the process, after the equilibrium phase, was smaller for the circular spreader $\pm1°F$ than for the cross spreader $\pm2°F$.

The results of the heating rate of containers study using 90% steam-10% air and 30 cfm of air flow indicated that the heating pattern for the tests for both spreader systems was, in general, similar. The fastest heating cans in the retort were in planes 1 and 2. In the circular spreader tests, the containers heated more rapidly than the containers in the cross spreader tests. The time for the containers to reach $\Delta T=3.6°F$ ranged from 6.5 to 9.5 min and to reach $\Delta T=1.8°F$--7.3 to 14.0 min for the circular spreader compared to 9.0 to 13.0 min to reach $\Delta T=3.6°F$ and 10.0 to 20.0 to reach $\Delta T=1.8°F$ for the cross spreader tests. The difference in the heating times among containers in the same plane was largest in the cross spreader tests. In the cross spreader tests, the containers in the center of the planes heated more slowly than containers at the periphery whereas, in the circular spreader tests the containers at all points in the plane heated relatively uniformly. The slowest heating container in the circular spreader tests was located directly opposite the dump valve line inlet, can 12, which required 14 min to reach $\Delta T = 1.8°F$ whereas the slowest heating container in the cross spreader test was in the center of plane 3, can 6, which required 20.0 min to reach $\Delta T=1.8°F$.

Comparisons of the temperature distribution data for the tests using 75% steam-25% air mixtures with 20 cfm air flow showed that the temperature drops when air was added to the retort were greater for the tests made with the cross spreader, $28°F$, than for tests with the circular spreader, $8°F$. The circular spreader reached an equilibrium temperature of $240\pm2°F$ 19 min after steam on whereas the cross spreader required 25 min to reach $240\pm5°F$. The temperature difference between points was greater in the cross spreader tests than in the circular spreader tests.

The heating rate data for the 75% steam-25% air with 20 cfm of air flow tests showed the same general pattern for both the cross and circular spreaders. In both cases, the hot zone was located in plane 4 at the top of the retort; can 4, in the center of plane 2 for the cross spreader and can 5, in the center of plane 2 for the circular spreader were the slowest heating containers for both types of spreaders. There were greater differences in the time to reach $\Delta T=3.6$ and $1.8°F$ between cans in the cross spreader tests than in the circular spreader tests; however, there were large time differences between containers for both tests. The time for the containers to reach $\Delta T=3.6°F$ ranged from 11.0 to 28.0 min and for $\Delta T=1.8°F$, 13.0 to 39.0 min in the cross spreader tests, and 5.0 to 20.0 min to reach $\Delta T=3.6°F$ and 6.0 to 26.0 min to reach $\Delta T=1.8°F$ in the circular spreader tests.

The temperature distribution tests for 75% steam-25% air with 30 cfm of air flow showed a maximum temperature drop at air inlet, 24°F for the circular spreader and 26°F for the cross spreader. The time for the points in the retort to approach $240\pm1°F$ for the circular spreader was 19 min after steam on while in the cross spreader tests 24 min were required after steam on to reach $240\pm4°F$.

The heat penetration data for 75% steam-25% air with 30 cfm of air flow for both spreader systems indicated that the circular spreader produced more uniform heating than the cross spreader. The heating rate of the containers for both tests showed that there were very large temperature differences among containers at the different planes and the times for the fastest vs. slowest heating container to reach $\Delta T=3.6°F$ ranged from 6.5 to 24+ min and to reach $\Delta T=1.8°F$ 8.5 to 28+ min for the cross spreader tests, whereas for the circular spreader tests the times to reach $\Delta T=3.6°F$ ranged from 4.0 to 19.0 min and to reach $\Delta T=1.8°F$ 5.0 to 22+ min. Can 6, at the center of plane 3, in the cross spreader test was the slowest heating undoubtedly because the temperature at this point did not reach $\Delta T=3.6°F$ during the process. In the circular spreader tests the slowest heating cans were 7, 9 and 12 at the periphery of planes 3 and 4 which did not reach $\Delta T=1.8°F$. In the cross spreader tests the cans in the two bottom planes heated fastest with relatively uniform heating. The cans in the two top planes had large come up times and some of the points did not reach processing temperature. In the circular spreader tests the fastest heating took place at plane 1 with the containers in planes 2, 3 and 4 heating more slowly. However, the container adjacent to the dump valve line inlet, can 10, heated much faster than any other container in the retort.

When the circular spreader was used, the flow of the heating mixture took place through the annular space of the retort. This upward directed flow in the annular space resulted in downflow through the stack of cans, with the net result that circulation was promoted. When the cross spreader was used, in general, the flow was still up the annular area; however, some of the flow moved up the center and this had the net effect of partially blocking natural circulation.

Discussion of the Results Obtained With Water Processes

Water processes were studied using two types of spreaders and three air flow rates. The come-up-time of the retort and the heating rate of the containers in the retort was quite different when a water process was used compared to the results obtained when steam-air or steam was used as the heating medium, due to the greater heat capacity of the water which resulted in a much longer come-up-time for the same basic steam flow and retort load. The time required for the first point in the retort to reach the process temperature was two times as long for the water cook than for the 100% steam or steam-air process.

In these tests which were very severe and designed to pinpoint differences in the heating rate a convection heating product, water, was used because it absorbed heat very rapidly. The heating rate tests indicated that the water in the containers heated almost as fast as the water in the retort. For example, at the end of approximately 4 min the average retort water temperature was 133°F, where in a comparable steam or steam-air test at the end of the 4 min vent period the heating medium temperature ranged from 185 to 217°F. The 303x406 cans of water lagged behind the heating medium, water, in the retort by as much as 36° during the first few minutes; however, by the time the water in the retort reached 212°F, the temperature of the water in the cans was approximately 194°F, lagging the temperature of the heating medium by only 18°F. By the time the water in the retort reached 230°, the temperature of the water in the cans was lagging only by about 11°F. The fact that the temperature of the product in the container follows closely on the heels of the temperature of the heating medium, in water processes, results in a heat penetration curve that only approaches the straight line asymptote toward the very end of the heating period. In general, these plots can be described as long sweeping curves that increased in steepness as the heating medium approached processing temperature.

Increasing the air flow rate decreased the time for the first point in the retort to reach temperature, decreased the point-to-point temperature variation, and decreased the time necessary for all points in the retort to reach equilibrium temperature. Increasing the air flow rate from 10 to 20 cfm produced a greater overall effect than a subsequent increase in the air flow rate from 20 to 30 cfm. Nevertheless the 30 cfm test heated fastest and temperatures were the most uniform as shown by the relative time to reach $\Delta T=3.6$ and 1.8°F shown in Table 3D2-1 . Obviously the increased air flow rate increased the water circulation rate, but the spreader design had an effect in addition to the air flow rate, since the cross and circular spreader produced different results. The action of the air in promoting water circulation was by the production of a low pressure area in the retort, flow being the direct result of a pressure difference. The pressure difference was produced when bubbles of gas displaced the water. Apparently in the range of air flow rates studied. increasing the air flow rate produced greater pressure differences and increased water flow. Flow patterns are shown in Figures 3D2-1 and 3D2-2.

The results suggested that while the effect of increased air flow was to improve retort performance when both the cross and circular spreaders were used, the circular spreader produced a greater volume of water circulation per volume of added air than did the cross spreader. The circular spreader was designed so the upward flow of water in the vertical retort during heating will be in the annular area between the retort basket and retort wall, and down flow will be through the basket and around the cans (Fig. 3D2-2). The circular spreader discharged at the bottom of this annular area and aims the steam and air upward toward the top of the retort (Fig. 3D2-4). When the cross spreader was used, the major gas and water flow path was apparently out to the edge under the bottom crate then up the annular area to the top of the retort. The

difference in the effectiveness of the two spreaders is in efficiency of using the gas for producing pressure differences, the relative times to reach $\Delta T = 3.6$ and $1.8°F$ tabulated in Table 3D2-1 is a measure of the relative effectiveness of the spreaders. (Table 3D2-1). Undoubtedly in the cross spreader some of the gas moves up through the baskets and in effect acts against flow created by the gas moving up the annular area (Fig. 3D2-3); if the gas were distributed uniformly across the bottom of the retort theoretically there will be no water flow.

The heating rate data indicated that the flow pattern of the heating medium using the cross spreader was around the periphery of the baskets rather than through the stack of containers which is in contrast to the common belief in the food industry, that the cross spreader stimulates flow up through the stack of cans. The highest temperatures in the retort were in plane 1 above the spreader. The temperature in this area was 3·to 5°F above the processing temperature during the period when there was considerable steam flow into the retort and the retort was approaching heating medium temperature. This was possible because the total pressure in the system at this time was about 18 psig which will support a vapor temperature of 255°F and since there was probably insufficient mixing in this bottom area due to a lack of a positive method of moving the water there was a heat concentration area at the edge of the bottom crate. A general description of what may be going on in this area is as follows: The space below the bottom basket and around the arms of the cross spreader may become essentially an area of gas bubble eddies. When the gas is discharged from the spreader it will try to rise to the liquid surface only to be swept downward and outward by the liquid flow. The gas will move in these eddies until it is carried to the periphery of the basket where it can rise to the surface with the upflow in the annular area. As the temperature of the water in the retort approaches the process temperature, the rate of heat flow from the vapor to the water decreases and we actually have bubbles of vapor at a high temperature that exist for a considerable period of time at least in the vicinity of the steam inlet. This high temperature vapor undoubtedly results in high temperature liquid in the immediate surrounding area that may persist for several minutes due to poor flow conditions.

The difference in retort performance as a function of the type of spreader must be due to the volume of water moved per volume of air. The advantages of the circular spreader are: the pressure reduction effect is concentrated in the annular area and more steam will be available to add to the effect. The disadvantages of the cross spreader are: some of the gas will try and move up through the baskets countering the overall effect and some of the steam will condense in the bottom reducing the overall pumping effect. For the same air flow rate, when the circular spreader was used, the time for the first point in the retort to reach temperature was reduced, the time for all points to reach processing temperature was reduced and the point-to-point temperature variation was reduced compared to the cross spreader (Table 3D2-1). The heat transfer film coefficient for water has been shown (McAdams, 1954) to be a function of the velocity of the water past the heat transfer surface. It is not surprising therefore to find that the containers heat faster for the same air flow rate when the circular spreader was used compared to the cross spreader. The larger h due to the more rapid circulation of fluid past the container causes a larger heat flux to the container. Therefore heating will be faster and a greater lethality will be accrued by the product in the containers. Figure 3D2-5 shows the lethality received at each position for the two spreader systems. The lethality values in this figure clearly point out the effect of higher heating medium velocity. The greatest difference was found between the cross and circular spreaders for 10 cfm of air flow.
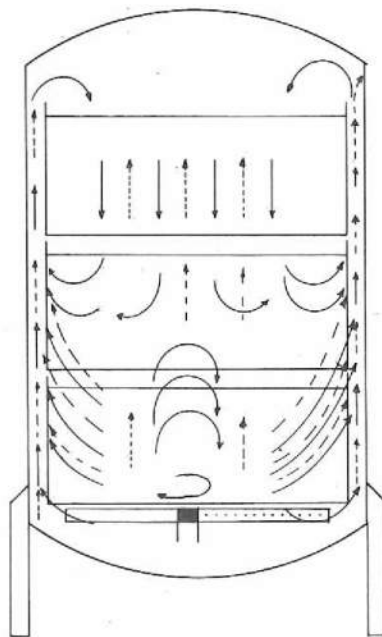
Figure 3D2-1. Flow profile for water cook tests with the cross spreader in the vertical retort.
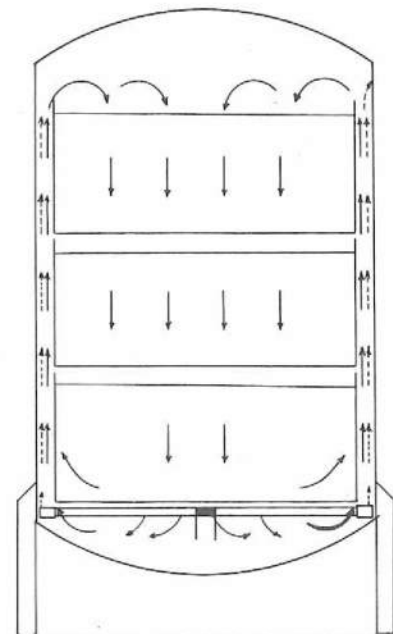
Figure 3D2-2. Flow profile for water cook tests with the circular spreader in the vertical retort.
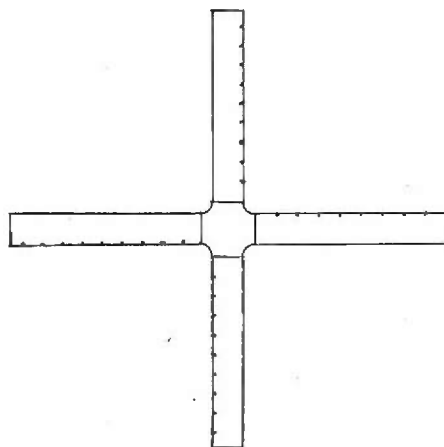
Figure 3D2-3. Schematic of the cross spreader.
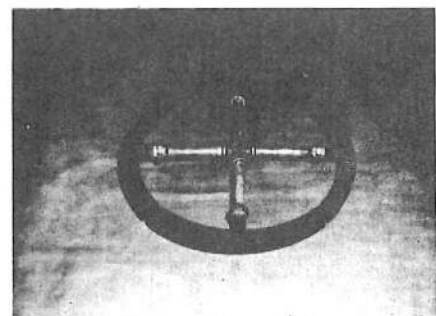
Figure 3D2-4. Photograph of the circular spreader.

Table 3D2-1. Heating rates of cans for the slowest and fastest heating cans in the water processes in a vertical retort.

Air flow rate	Spreader	Can No.	Time for the containers in the retort to reach		Can No.	Time for the containers in the retort to reach	
			$\Delta T=3.6°F$	$\Delta T=1.8°F$		$\Delta T=3.6°F$	$\Delta T=1.8°F$
10 cfm	Circular	2	14.0	16.0	10	9.5	10.0
	Cross	8	19.0	21.0	1	16.0	17.0
20 cfm	Circular	2	12.5	13.5	10	10.0	10.3
	Cross	5	16.0	18.0	2	14.0	14.5
30 cfm	Circular	2	11.5	.12.5	11	9.8	10.0
	Cross	8	13.0	14.5	2	12.0	12.5
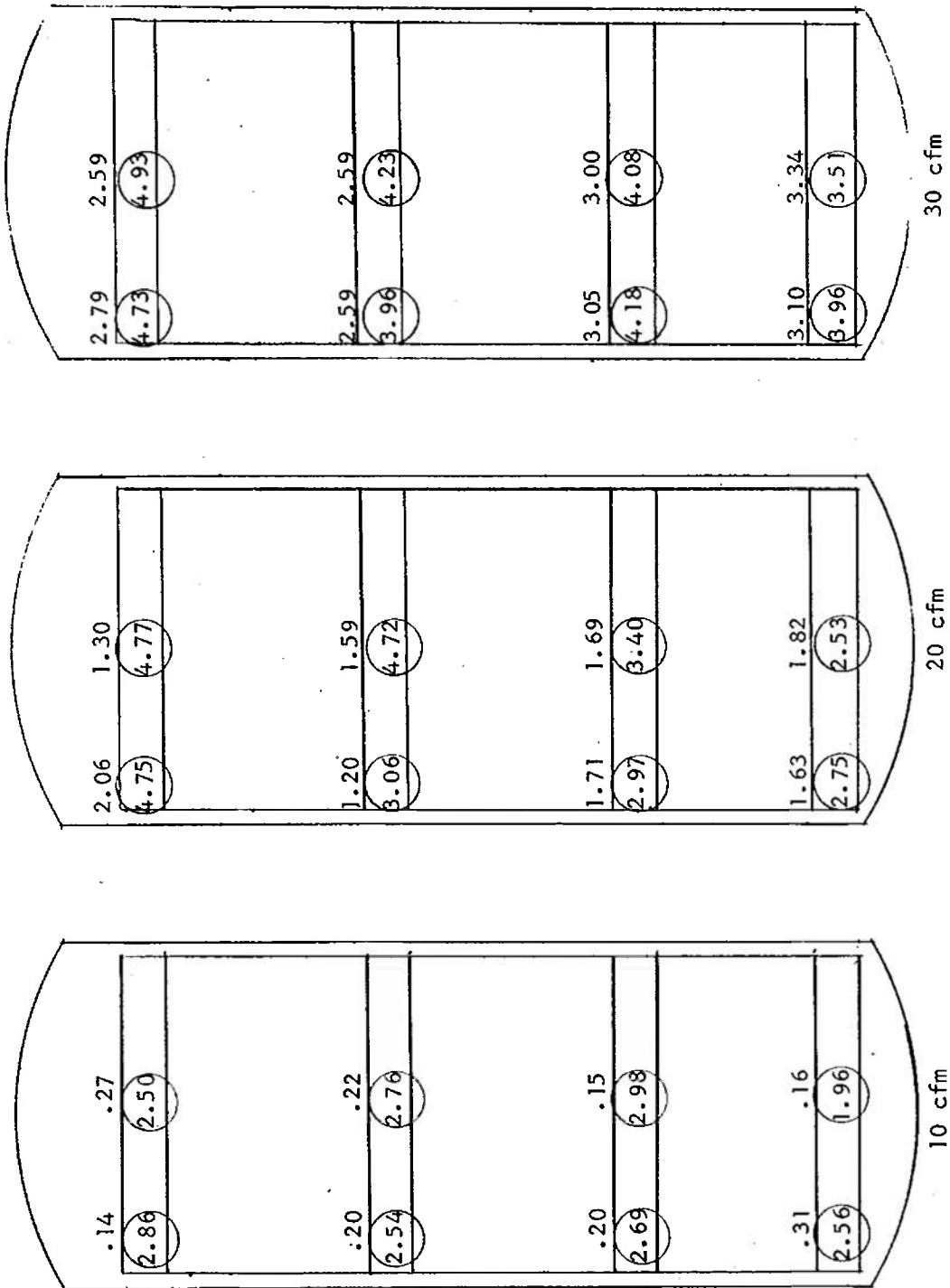
Figure 3D2-5. Diagram of the vertical retort showing the lethality received by the measuring container at each position in the retort, expressed as min at 240°F, for the same length of time during the water cook process using the circular and cross spreaders with three air flow rates. The number in the circle at each measuring position is the lethality value for the circular spreader test and the number above it the value for the cross spreader test.

4. Horizontal Retort Tests

4A. Design of the Experiment

The horizontal retort experiments were designed to parallel the vertical retort tests. The variables considered were: the size of the retort load, number and location of thermocouples, and basic retort modifications.

The basic retort operating procedures and control methods developed for the vertical retort tests were used in the horizontal retort tests. The standard horizontal retort test load was 1150 303x406 cans of water. Temperatures were measured in three planes; in the top, center, and bottom layers of cans in the baskets. The temperatures were measured in three positions in each plane. In the preliminary tests only bare thermocouples located in several positions in the retort were used; these tests were made to establish procedure and to insure the operation of the retort components. In the final tests a pair of thermocouples was located at each temperature measurement point, a rod-type thermocouple in a can and a bare thermocouple adjacent to this can.

The heating media used for these experiments were the same as those for the vertical retort tests: 100% steam, 90% steam-10% air, 75% steam-25% air, and water. The rate of air flow was controlled by a rotameter and air flow rates from 10 to 30 cfm were evaluated in the steam-air and water processes.

A 3/4 in. proportional valve was added to the retort in order to vent during the steam-air processes. This valve was found necessary to maintain optimum pressure control and was also used for venting the heating mixture during the process.

The retort load was reduced by 50% for some of the tests. This reduced load condition was approximately that found when a horizontal retort was fully loaded with flexible packages. The effect of retort load on the efficiency of the heating medium was evaluated by this procedure. Mechanical circulation of the heating medium using a gas pump was studied for a limited set of conditions.

In a similar manner to the vertical retort tests the heating rate data did not lend themselves to direct analysis by Ball and Olson's (1957) f and j values. The plots of the heating rate curves on three-cycle semi-logarithmic paper did not yield straight lines; therefore the data will be presented as a group of temperature distribution graphs and tables of the times required for the containers to reach $\Delta T=3.6$ and $1.8°F$. These tables enable the reader to evaluate the efficiency of the heating medium at the various locations and compare the processes.

4B. Experimental

Equipment

The retort used for this phase of the study was a 2-crate 3.5 ft. diameter by 7 ft. long horizontal pressure retort fabricated in 1950 for use in high pressure canned food processing. The system was provided with 90 psig steam pressure and 50 psig water pressure. The steam lines were nominal 1-1/4" steel pipe with 2" steel pipe drain and dump lines. The retort was initially controlled by an on-off temperature controller and proportional pressure controller.

The retort control system was modified to improve the operation of the retort system. The modifications were as follows:

1. A 3/4" proportional type air control valve was installed in the retort steam feed line in parallel with a hand operated 1-1/4" globe valve.

2. A proportional type temperature controller using a thermocouple sensing element was installed to operate the 3/4" proportional steam valve.

3. An air flow meter with a hand valve for manual control of air flow rate was installed in the air feed line (Brooks Rotameter Model No. 1100, range 5-100 cfm.).

4. A proportional type pressure controller was installed to operate the 3/4" proportional pressure bleed valve.

A schematic diagram of the retort and control system is shown in Fig. 4B1-1. The 3/4" steam valve actuated by a proportional controller with a thermocouple sensing element was designed to limit the rate of steam flow into the retort upon the opening of the control valve. This was done in two ways: 1) The rate of flow of steam through the valve was reduced by decreasing the valve size; and 2) using a thermocouple sensing element, the controller actually responds faster thus eliminating cycling of the system. To help eliminate cycling in the system, the controller was adjusted to throttle the inlet valve until there was a continuous flow of steam entering the retort. The valve in the 1-1/4" line was used only during the come up phase of the process; the 1-1/4" globe valve was closed as soon as the system reached temperature and control of the process relegated to the 3/4" valve. The use of a rotameter in the system allowed the study of steam-air mixtures of 10 to 30 cfm air flow rate. The air passed directly from the rotameter to the spreader and the air flow rate was adjusted manually for each process.

Venting during the come-up phase of the process was made through a 1" top vent pipe with a hand valve, venting of the retort lasted 4 min or until the retort reached 220°F, whichever came last. Pressure in the retort was controlled by a proportional controller through a 2" dump valve. This system, however, did not prove satisfactory for steam-air mixtures because the valve was too large and throttling the valve to bleed a continuous quantity of the heating mixture,and at the same time control the pressure,was not possible. To maintain continuous flow, a 3/4" proportional valve controlled by a proportional controller was installed in parallel with the 2" dump valve. The controller was throttled to bleed the gas mixture during the process. The pressure control with the 2" valve was used as a secondary control if the 3/4-in. valve could not handle the flow and during the cool.

The cool cycle of the retort was performed manually. The water level in the retort for water processes and during all cool cycles was indicated by a watch glass attached to the side of the retort. During the water cook or water cool the pressure in the retort was maintained by means of the dump valve.

The steam-air heating media were studied under forced circulation of the steam-air mixture for all heating mixture conditions. The gas pump used in this case was a Roots Connersville Blower 47XA pump operated at 77 cfm. The gas mixture was taken from the top of the retort through a 1-1/2" pipe and discharged into the bottom of the retort through the steam spreader along with the steam and air supply.

The retort was loaded with 1150 303x406 cans filled with water, a convection heating product, producing the greatest heating load for the retort or the most critical heating conditions. The cans were carefully stacked in the baskets to obtain maximum capacity.

Temperatures were measured using copper constantan thermocouples and a multi-channel one minute cycle temperature recording potentiometer. The thermocouples were located in three planes with three positions in each plane. A thermocouple was placed on the inside of the container and another on the outside of the container at each of the positions shown on Fig. 4B1-2. The first plane was in the first layer of cans, points 1, 2 and 3; plane 2 was in the third layer of cans, points 4, 5 and 6; and plane 3 was in the sixth layer of cans, points 7, 8 and 9. The plain thermocouples were united to a common ground, the rod-type thermocouples in the containers were grounded to the packing gland. One gram of salt was added to each container of water used in the measurement of heat penetration rates.

Experimental Procedure

The initial phase of the testing procedure as in the case of the vertical retort tests was the assembling and testing of the equipment making up the system. At the start of tests the retort baskets were carefully hand-stacked with the cans of water including the cans with thermocouples which were placed at the several designed locations. The filled retort baskets were pushed into the retort and when the baskets were in place, thermocouple leads were formed into a cable and brought out of the retort through the special stuffing box and connected to the potentiometer cable.

The measurement of temperature in the retort was made with a multi-channel potentiometer with an accuracy of $\pm 0.2°F$ or $\pm 0.1°C$. The process was timed by a digital clock. The process time was usually 25 min; however, the slower heating processes were run for a longer time to have equal opportunity to equilibrate. The initial temperature of the retort and contents was $80 \pm 10°F$. In the steam-air tests the air was let in after the retort reached temperature as explained above for the vertical retort. The cooling processes were the same for all the heating tests. The retort was cooled until the containers reached $80 \pm 10°F$.

The fully loaded horizontal retort described above was used to make replicate tests for the several air flow conditions for each of the three heating media; the specific procedure was as follows:

100% steam.

1. The proportional temperature controller was set for 240°F. The pressure controller was set for 13 psig and the top 1" vent was opened.

2. Steam was turned on through the 3/4" proportional valve and the 1-1/4" globe valve. The duration of the vent was 4 min or until the retort reached 220°F, whichever came last. At the end of this time the vent was closed.

3. When the retort reached 240°F, the 1-1/4" manual globe valve was closed and temperature control relegated to the 3/4" proportional valve. The retort was bled continuously.

4. At the end of the heating cycle the bleeds were closed, the steam turned off, and the water introduced through the spreader for the cool cycle. The pressure in the retort was maintained at 13 psig throughout the cool cycle. The level of the water was controlled by observing the water level indicator.

Steam-air.

1. The temperature controller was set at 240°F. The proportional pressure controller for the 3/4" proportional bleed valve was set at 13 psig for 90% steam-10% air and at 18 psig for 75% steam-25% air. The top vent was opened.

2. The 1-1/4" globe steam valve and the 3/4" air operated steam valve were opened.

3. At the end of 4 min or when the retort reached 220°F, whichever came last, the top vent was closed.

4. When the retort reached 240°F the 1-1/4" globe valve was closed, the temperature control was relegated to the proportional controller activating the 3/4" proportional steam valve. At this time the air was turned on at the desired air flow rate.

5. The cook cycle proceeded with the retort venting continuously through the 3/4" air operated proportional vent valve located in the top of the retort. This valve was actuated by the proportional pressure controller.

6. At the end of the cook cycle the on-off pressure controller was set for 13 psig, the steam was turned off, the top 3/4" proportional vent was closed and water was introduced into the bottom of the retort. The level of the water was controlled manually by observing the water level in the retort through the indicating watch glass.

100% steam and steam-air with mechanical circulation.

The procedure for steam-air cooks using mechanical circulation of the heating mixture was the same procedure as above with the following modifications.

1. When the retort reached 240°F and the 1-1/4" steam valve was closed, the mechanical gas pump was vented until all the water in the line was expelled. The pump was then turned by hand to assure free movement, no water entrained in the pump.

2. The pump was then started, run for 30 sec. and then the air was introduced into the retort.

3. At the end of the cook cycle the pump was turned off 30 sec. before steam off.

4. The cool cycle proceeded as described above for a regular steam-air process.

Water processes.

1. The retort was closed and then filled with water to the water level mark on the retort watch glass.

2. The proportional temperature controller was set for 240°F; the pressure controller was set for 18 psig. The air was introduced through the spreader at the bottom of the retort. The pressure controller maintained pressure by modulating the dump valve.

3. The air was turned on at the rotameter to introduce 10, 20, or 30 cfm of air, the 1-1/4" steam valve and the 3/4" air operated steam valve were opened.

4. When the retort reached 240°F, the cook cycle began, the 1-1/4" valve was closed and the temperature in the retort was controlled by the potentiometer controller through the 3/4" proportional steam valve.

5. At the end of the cook cycle, the steam was turned off and the cooling water to the retort introduced. The pressure in the retort was maintained by the 2" dump valve. Since cooling in this retort was performed manually, care was taken to keep the water level in the retort at the specified level on the watch glass to keep the retort from becoming hydrostatic where the pressure in the retort would damage the containers.

Analysis of Data

The data obtained from these tests were of two types: the temperature distribution data obtained from the plain thermocouples, and the container heating rate data which were obtained from the rod-type thermocouples.

The temperature distribution data were plotted temperature vs. time on an arithmetic grid, and the heating rates of containers data plotted on three-cycle semi-logarithmic paper by the method of Ball and Olson (1957). The analysis of these charts was made in the same manner as for the vertical retort tests.

Safety valve

1-in. vent

3/4-in. dump line

2-in. dump line

1-1/2 in.

Steam spreader 1-1/2 in.

2-in. drain

Water line
1-1/4 In.

Steam 1-1/4 in.

3/4-in. valve

Gas pump

1-1/2 in.

Rotameter

Air
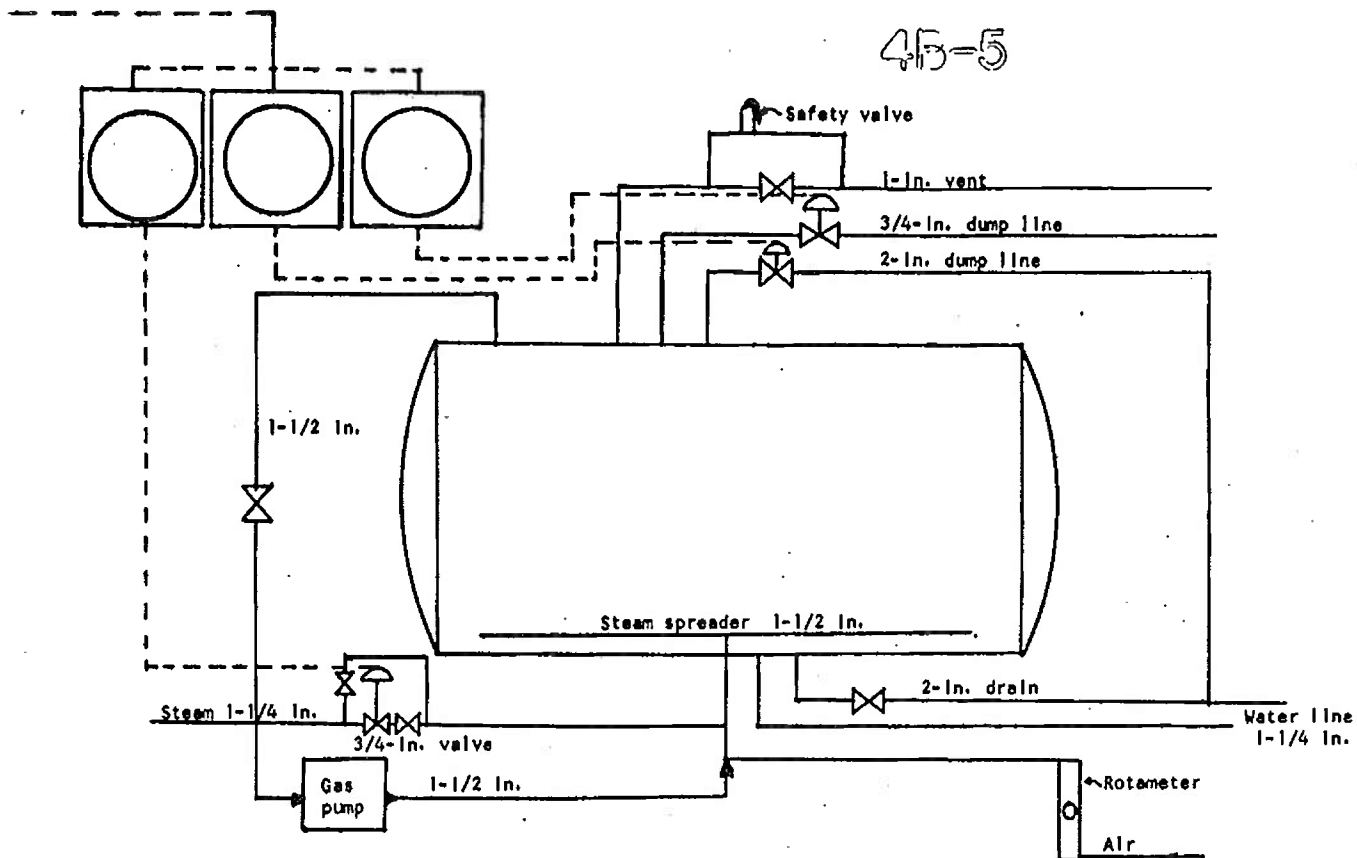
Figure 4B1-1. Schematic diagram of horizontal retort.
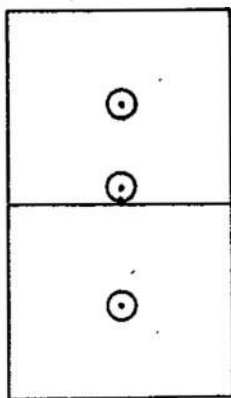
Top view of horizontal retort baskets indicating placement of cans for each plane.
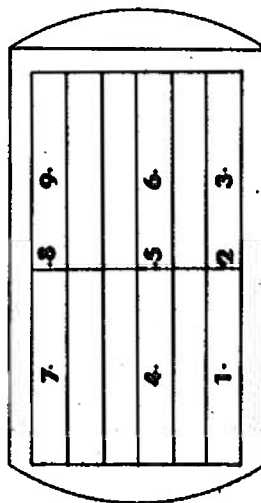
Side view of horizontal retort showing the six layers of cans and thermocouple placement.

Figure 4B1-2. Diagram of thermocouple placement in the horizontal retort.

Temperature Distribution Studies in a Horizontal Retort

Temperature distribution studies in a horizontal retort under full load.

The data from the temperature distribution tests in the horizontal retort were plotted temperature vs. time on a linear grid. Using these charts, subjective comparisons were made between the different heating conditions with respect to the time to approach equilibrium processing temperature and uniformity of temperatures throughout the retort during the process. Studies of steam, steam with various concentrations of air, and water were made. For steam-air and water the effect of air flow rate on the heating medium properties was studied.

The results of the temperature distribution tests made on the horizontal retort will be explained below in the order of decreasing steam concentration and increasing air flow rate.

100% steam.

The results of tests using 100% steam as the heating medium are shown in Fig. 4C1-10. All temperatures in the retort were at $240\pm1°F$ as soon as first point in the retort reached 240°F (Table 4C1-1), and with the exception of point 1 all points were at $240\pm0.5°F$ as soon as the first point in the retort reached processing temperature. The temperatures throughout the retort were maintained at 240°F during the process.

90% steam-10% air.

The results of the temperature distribution tests of 90% steam-10% air with an air flow rate of 10 cfm are shown in Fig. 4C1-1. The first point to reach processing temperature was point 8. The flow of air into the retort caused a drop in temperature at the bottom two planes with can 6 having the largest temperature drop, 7°F. All points in the retort were at $240\pm2°F$ 3 min after the first point reached processing temperature and at $240\pm1°F$ 4 min later (Table 4C1-1). All points reached $240\pm0.5°F$ during the next 2 min and remained at this temperature for the duration of the process.

Increasing the air flow rate from 10 to 15 cfm with a 90% steam-10% air heating mixture increased the temperature drop upon introduction of the air into the retort. The points which dropped in temperature were located in the first two planes, cans 1, 2, 4, 5 and 6. The largest drop was at point 2 in plane 1. The retort reached $240\pm2°F$ 4 min after the first point reached processing temperature and $240\pm1°F$ 1 min later. The difference between 10 and 15 cfm of air was hardly discernible; therefore, only the 10 cfm chart is included in this report.

The results of the test using 90% steam-10% air with 20 cfm of air flow are shown in Fig. 4C1-2. The come up phase of this test was similar to the 10 cfm test. Point 7 was the first point to reach 240°F. The introduction of air into the retort caused a drop in temperature in the first two planes. This temperature drop was more significant at positions 2 and 5, which were adjacent to the channel caused by the separation between the baskets. All points in the retort were at $240\pm2°F$ 3 min after the first point reached processing temperature and at $240\pm1°F$ 1 min later (Table 4C1-1).

The results of 90% steam-10% air with 30 cfm of air flow are represented by Fig. 4C1-3. The first point to reach processing temperature was point 1 in the bottom plane. The addition of air to the retort caused a more severe temperature drop for this case than for the other processes. The combination of the large air flow rate into the retort

and the slow temperature response due to the small steam line and relatively low boiler steam pressure caused a significant lag in the time for the retort to reach processing temperature. All points in the retort were at 240+2°F 3 min after the first point reached 240°F and at 240+1°F 2 min later (Table 4C1-1).

75% steam-25% air.

The 75% steam-25% air mixtures were studied for 10, 20 and 30 cfm of air. The 10 cfm tests were included in the report even though the retort took 3 to 4 min to reach processing pressure. The results of the 75% steam-25% air test using 10 cfm of air are represented by Fig. 4C1-4. The first point to reach processing temperature was point 11. The air was then added to the retort with a subsequent temperature drop in the first two planes, points 1, 2, 3, 4, 5, and 6. The lowest temperature reached was 232°F, points 1 and 6, but the temperature recovered quickly with all points reaching 240+2°F 13 min after the first point reached processing temperature and 240+1°F 2 min later (Table 4C1-1).

The 20 cfm tests of 75% steam-25% air heating mixtures (Fig. 4C1-5) behaved in a similar manner as the 10 cfm test except for point 6. The introduction of air to the retort caused a large temperature drop in the lower two planes. The largest drop was at point 6, 12°F. This point approached the processing temperature slowly and reached 240+2°F 11 min after the first point reached processing temperature (Table 4C1-1). All other points were at 240+2°F 8 min after the first point reached processing temperature.

The results of the tests with 30 cfm of air in 75% steam-25% air are shown in Fig. 4C1-6. The general pattern for this test was similar to that for the two previous 75% steam-25% air heating conditions; however, in comparison to the 20 cfm test the largest temperature drop occurred at point 1 with a drop of 9°F. The retort reached a temperature of 240+2°F 9 min after the first point reached 240°F, and 240+1°F 2 min later (Table 4C1-1). Point 6 in this test was low throughout the initial part of the test; however, it was not comparable to the 20 cfm test. In a manner similar to the two other tests the coldest region in the retort was in the first two planes in the retort at points 1, 2, 3, 4, 5, and 6.

Water

Water processes were studied at 240°F and at air flow rates of 10, 20 and 30 cfm. The operating pressure was 18 psig and the air was metered into the retort through the steam spreader starting when the steam was turned on.

Figure 4C1-7 represents the results of the water process tests with an air flow rate of 10 cfm. The come up of the water process differed markedly from that of the steam and steam-air processes. The time necessary for the first point to reach processing temperature in the water cook was 3 times that of the steam and steam-air processes. The reason for this difference was the high heat capacity of the water. The heat load of the retort filled with water was at least twice as large as the empty retort heat load. The quantity of steam available to the retort was limited by the size of the steam pipes and the boiler pressure ; therefore, the steam available per unit time was one of the limiting factors in determining the length of come up for the water process. The high heat capacity of the water and the poor flow characteristics of the heating medium caused a peak in the temperature and then cycling of the temperature until the retort approached process temperature. In the 10 cfm test points 1, 3 and 4 were as much as 8°F above the desired 240°F temperature. All points in the retort were at

240+2°F 3 min after the first point in the retort reached processing temperature and at 240+1°F 5 min later (Table 4C1-1).

Figure 4C1-8 represents the results of the water process with an air flow rate of 20 cfm. This chart shows that the higher air flow rate decreased the time for the first point to reach processing temperature by 1 min. The temperature over-shoot for this higher air flow rate was smaller; all points were at 240+2°F 2 min after the first point reached processing temperature and 240+1°F 2 min later (Table 4C1-1).

The 30 cfm air flow caused a substantial decrease in the time for the first point to reach processing temperature but in this case there were also large temperature fluctuations as soon as the retort reached processing temperature as shown in Fig. 4C1-9. Table 4C1-1 indicates that all points in the retort were at 240+1°F 5 min after the first point reached processing temperature.

Temperature Distribution Studies in the Horizontal Retort with Mechanical Circulation of the Heating Medium

The study of steam-air as a heating medium has indicated that a high rate of circulation is necessary to obtain uniform temperatures in the retort. To achieve this end the gas pump was installed and used to evaluate the 90% steam-10% air and 75% steam-25% air both with 10 cfm of air flow. The circulation rate was 77 cfm.

90% steam-10% air.

The results of the temperature distribution tests of 90% steam-10% air with 10 cfm of air flow circulated at a rate of 77 cfm showed the temperature drop at the air inlet to be 3°F at points 4 and 6 (Fig. 4C1-11). The retort reached 240+2°F 3 min after the first point reached 240°F, and 240+1°F 1 min later (Table 4C1-2). All points in the retort were at the processing temperature during the duration of the test.

75% steam-25% air.

The results of the temperature distribution tests for the 75% steam-25% air with 10 cfm air flow and circulation by the gas pump of 77 cfm are shown in Fig. 4C1-12. The maximum temperature drop at air inlet was 15°F at point 1 with points 1, 2, 4, 5 and 6 in the first two planes having lower temperatures than the other points. The retort reached 240+2°F 9 min after the first point reached 240°F and 240+1°F 7 min later (Table 4C1-2).

Temperature Distribution Studies in the Horizontal Retort with 50% Load.

The heating load of a retort determines the time necessary for the retort to come up to temperature because of the amount of heat which must be supplied by the steam to the containers in order for the retort and contents to reach processing temperature. The heating load for all tests in the horizontal retort was 1150 303x406 cans of water which was 150 cans more than the customary load. This condition was studied because the come-up-time and temperature variation in the retort are usually increased with the heat demand rate of the retort load. We can assume that if the heating load of the retort is reduced the heating conditions will improve. To ascertain this fact, the retort was loaded with 575 cans which were hand stacked in three layers in the two baskets. In each layer of cans were placed three cans with rod-type thermocouples and three with plain thermocouples in the same positions in the plane as for the maximum loaded retort, Fig. 4B1-2. The data obtained was plotted, temperature vs. time, on a linear grid and compared subjectively.

100% steam.

The results of the tests of 100% steam with 50% of the maximum retort load are shown by Fig. 4C1-13. The chart shows that all points in the retort were at processing temperature as soon as the first point reached 240°F. The time necessary for the first point to reach processing temperature was much shorter than for the fully loaded retort.

90% steam-10% air.

The results of the test of 90% steam-10% air with 10 cfm of air flow in the retort with 50% of the maximum load are shown in Fig. 4C1-14. The temperature distribution plot showed that there was a 6°F drop in temperature when the air was introduced into the retort. All points except for point 7 reached 240±0.5°F 2 min after the first point reached the processing temperature. All points were at 240±1°F 4 min after the first point reached 240°F.

75% steam-25% air.

The chart of the 75% steam-25% air test results of the retort loaded with 50% of the maximum load showed that the largest temperature drop was upon the introduction of air into the retort, 4°F, that occurred at point 6 (Fig. 4C1-15). The retort reached 240±1°F 8 min after the first point reached processing temperature.

Figure 401-1. Temperature distribution in a horizontal retort using 90% steam—10% air at 240°F with 10 cfm of air flow.

Figure 401-2. Temperature distribution in a horizontal retort using 90% steam—10% air at 240°F with 20 cfm of air flow.

Figure 401-3. Temperature distribution in a horizontal retort using 90% steam—10% air at 240°F with 33 cfm of air flow.

Figure 4C14. Temperature distribution in a horizontal retort using 75% steam-25% air at 240°F with 10 cfm of air flow.

Figure 4C1-5. Temperature distribution in a horizontal retort using 75% steam-25% air at 240°F with 20 cfm of air flow.

Figure 4C1-6. Temperature distribution in a horizontal retort using 75% steam-25% air at 240°F with 30 cfm of air flow.

Figure 4C1-7. Temperature distribution in a horizontal retort using a water cook at 240°F with 10 cfm of air flow.

Figure 4C1-8. Temperature distribution in a horizontal retort using a water cook at 240°F with 20 cfm of air flow.

Figure 4C1-9. Temperature distribution in a horizontal retort using a water cook at 240°F with 60 cfm of air flow.

Figure 4CI-10. Temperature distribution in a horizontal retort using 100% steam at 240°F.

Figure 4CI-11. Temperature distribution in a horizontal retort using 90% steam-10% air at 240°F with 10 cfm of air flow and a recirculation rate of 77 cfm.

Figure 4CI-12. Temperature distribution in a horizontal retort using 75% steam-25% air at 240°F with 10 cfm of air flow and a recirculation rate of 77 cfm.

Figure 4C1-13. Temperature distribution in a horizontal retort using 100% steam at 240°F, 50% retort load.

Figure 4C1-14. Temperature distribution in a horizontal retort using 90% steam–10% air at 240°F with 10 cfm of air flow and a 50% retort load.

Figure 4C1-15. Temperature distribution in a horizontal retort using 75% steam–25% air at 240°F with 10 cfm of air flow and a 50% retort load.

Table 4C1-1. Time for all points in the horizontal retort to reach 240 ± 5, 240 ± 2, and $240\pm1°F$

	Time after the first point reached 240°F (min)			Time from start of heating (min)
	$240\pm5°F$	$240\pm2°F$	$240\pm1°F$	$240\pm1°F$
100% steam				9
90% steam-10% air				
10 cfm	1	3	4	12
15 cfm	1	4	5	13
20 cfm	1	3	4	11
30 cfm		3	5	13
75% steam-25% air				
10 cfm	5	13	15	23
20 cfm	9	11	13	21
30 cfm	3	9	11	19
240°F water cook				
10 cfm	2	3	7	30
20 cfm	1	4	4	25
30 cfm	5	5	5	23

Heating Rates of Containers in a Horizontal Retort.

The heat penetration data obtained, using rod-type thermocouples inserted in 303x406 cans of water, as part of the temperature distribution tests were plotted on semi-logarithmic paper according to the procedure of Ball and Olson (1957). In these studies, as in the vertical retort studies, the heating curves were not single straight lines; therefore, the heating rate data will be reported as the time to reach $\Delta T=3.6$ and $1.8°F$. The data in Tables 4C2-1 and 4C2-2 make possible relative comparisons of the effectiveness of location and heating medium.

Heating rate of containers in the fully loaded retort.

The operational procedure for the 100% steam, 90% steam-10% air, and 75% steam-25% air was identical until the retort reached processing temperature and the air was turned on for the steam-air processes.

100% steam. The heating rate data for containers in 100% steam in the horizontal retort indicated that there were two rates of heating. During the come up of the retort when the vent was open the heating curve for all the containers had a slope of approximately 10 min; however, when the vent was closed there was a break in the curve with the new curve having a slope of 3.0 to 4.0 min. Heating of the containers in the same plane was relatively uniform. The cans in the first two planes heated more slowly than the cans in plane 3. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 11.0 to 12.0 min and to reach $\Delta T=1.8°F$ 12.5 to 13.5 min (Table 4C2-1).

90% steam-10% air. The results of the heating rate study of 303x406 containers of water in 90% steam-10% air with 10, 15, 20 and 30 cfm of air flow in the horizontal retort indicated that there was a great deal of similarity in the heating curves for the containers among the several processes. The data for the 90% steam-10% air tests with 10 cfm of air indicated that this heating medium was quite similar to 100% steam in uniformity and rapidity of come up. The addition of the air caused a break in the heating curves with a larger second slope that only slightly increased the time to reach $\Delta T=3.6°F$, but caused a significant increase in the time to reach $\Delta T=1.8°F$. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 11.0 to 13.0 min and to reach $\Delta T=1.8°F$ 13.0 to 15.5 min (Table 4C2-1).

The 90% steam-10% air tests with 15 cfm of air flow showed a similar heating pattern to the 10 cfm tests. The fastest heating occurred in plane 3, cans 7, 8 and 9. Cans in planes 1 and 2 heated equally fast but with no defined pattern, the time for the containers in these two planes to reach $\Delta T=3.6$ and $1.8°F$ was 1 min longer than for the 10 cfm tests. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 11.0 to 14.0 min and to reach $\Delta T=1.8°F$ 12.0 to 17.0 min (Table 4C2-1).

The results of the tests of 90% steam-10% air with 20 cfm of air showed little differ-ence from the 10 and 15 cfm tests. Cans 1 and 4 in planes 1 and 2 were slowest heat-ing and were coincidentally on the same side of the retort. Containers 2, 3, 5, 6, 7, 8 and 9 heated as fast or faster than the cans in the 100% steam test, requiring 12.0 min for can 2 and 11.0 min for the remainder to reach $\Delta T=3.6°F$. The last break in the curve was approximately at a ΔT of $4°F$; due to this break the time to reach $\Delta T=1.8°F$ was greater for some of the containers. It was interesting to note that cans 7, 8 and 9 in plane 3 required the same average time to reach $\Delta T=1.8°F$, 12.5 min as the cans in the 100% test; however, some of the remaining cans in planes 1 and 2

heated more slowly and required as much as 3 min longer to reach $\Delta T=1.8°F$. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 11.0 to 14.0 min and to reach $\Delta T=1.8°F$ 12.0 to 16.5 min (Table 4C2-1).

Increasing the air flow rate from 20 to 30 cfm for the 90% steam-10% air heating medium did not decrease the time required for the containers to reach $\Delta T=3.6°F$ and 1.8°F. The containers in plane 1, cans 1, 2 and 3 heated in much the same manner as in the previous 90% steam-10% air heating medium tests; however, in the 30 cfm tests, cans 4, 5 and 6 in plane 2 required an average of 13.5 min which was similar to the 10 and 15 cfm tests, but slower when compared to the 20 cfm test. Cans 7, 8 and 9 in plane 3 required an average of 1 min longer to reach $\Delta T=3.6°F$ when the air flow rate was 30 cfm. The time required for the slowest vs. the fastest container to reach $\Delta T=3.6°F$ ranged from 11.5 to 13.5 min and to reach $\Delta T=1.8°F$ 14.5 to 17.5 min (Table 4C2-1).

75% steam-25% air. The results of the heating rate tests in 75% steam-25% air with 10 cfm of air showed a heating pattern which was quite different from the 90% steam-10% air tests. Due to the temperature drop caused by the introduction of the air into the retort, the heating rate of the containers varied widely throughout the retort. The fastest heating containers, cans 7, 8 and 9, were located in plane 3. Cans 4, 5 and 6 in the middle of the stack of cans were the slowest heating. The time required for the cans to reach ΔT of 3.6°F ranged from 11.0 to 23.5 min and for $\Delta T=1.8°F$ 12.5 to 31.0 min (Table 4C2-1).

Increasing the air flow rate from 10 to 20 cfm for the 75% steam-25% air process did not produce a substantial improvement in the heating pattern. The slowest heating cans were in plane 2; cans 4 and 6 requiring 25.0 and 29.0 min respectively to reach $\Delta T = 1.8°F$. This maximum time was smaller than that for the 10 cfm tests, 31.0 and 27.0 min for cans 4 and 6. Cans 7, 8 and 9 in plane 3 were the fastest heating containers, and required approximately the same time to reach $\Delta T=1.8°F$ as those in the same position for the 10 cfm tests. The times for the slowest vs. the fastest container to reach $\Delta T=3.6°F$ ranged from 11.5 to 24.0 min and to reach $\Delta T=1.8°F$ 13.0 to 29.0 min (Table 4C2-1).

The 30 cfm tests for 75% steam-25% air heating mixtures behaved in much the same way as the 10 and 20 cfm tests; the slowest heating occurred at plane 2; however, the maximum time to reach $\Delta T=1.8°F$ was shortened 2 min for the slowest heating container. The results indicated that can 9 in the third plane heated slower than the other cans in this plane. There was no significant change in the heating pattern in plane 1, cans 1, 2 and 3. The time for the fastest container vs. the slowest to reach $\Delta T=3.6°F$ ranged from 12.0 to 18.0 min and to reach $\Delta T=1.8°F$ 13.5 to 27.0 min (Table 4C2-1).

Water cooks. The results of the water cook tests using 10, 20 and 30 cfm of air flow in the horizontal retort indicated that the same type of heating of the containers existed as in the vertical retort tests.

The heating rate data from the water process using 10 cfm of air flow indicated that the differences in the time required for the fastest vs. slowest containers to reach $\Delta T=3.6°F$ was not large, 4.0 to 5.0 min. The slowest heating container in the retort was can 5 requiring 27.5 min to reach $\Delta T=3.6°F$ and 29.0 min to reach $\Delta T=1.8°F$. The fastest heating was can 1 in plane 1 which required 23.5 and 24.0 min to reach $\Delta T= 3.6$ and 1.8°F respectively. The remainder of the cans in the retort did not show a defined heating pattern nor were there large differences in the heating times. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 23.5 to 27.5 min and to reach $\Delta T=1.8°F$ 24.0 to 29.0 min (Table 4C2-1).

The 20 cfm air flow rate decreased the time required for the containers to reach $\Delta T = 3.6$ and $1.8°F$ by 1.0 and 1.5 min for each point. Can 5 in the center of plane 2 was the slowest heating container requiring 26.0 and 27.5 min to reach $\Delta T = 3.6$ and $1.8°F$ respectively. The heating pattern in the retort was not defined, but was rather uniform and the heating times among cans did not vary extensively. The time for the slowest vs. the fastest heating container to reach $\Delta T = 3.6°F$ ranged from 22.0 to 26.0 min and to reach $\Delta T = 1.8°F$ 22.5 to 27.5 min (Table 4C2-1).

The water cook processes using 30 cfm of air flow indicated that in a manner similar to the 20 cfm tests the increase in the air flow rate from 20 to 30 cfm of air decreased the time for the containers to reach $\Delta T = 3.6$ and $1.8°F$ by about 2.5 min. The slowest heating can for this process was also can 5 at the middle of plane 2; however, the time differences between the cans in plane 2 were not as large for the 30 cfm as for the 10 and 20 cfm air flow rates. The times for the fastest vs. the slowest heating containers to reach $\Delta T = 3.6°F$ ranged from 19.5 to 22.5 min and to reach $\Delta T = 1.8°F$ 20.0 to 25.0 min (Table 4C2-1).

Heating rates of containers in the horizontal retort with mechanical circulation.
The heating rate studies in the horizontal retort with mechanical circulation by the gas pump were made for both 90% steam-10% air and 75% steam-25% air for 10 cfm of air flow with a mechanical circulation rate of 77 cfm.

90% steam-10% air. The heat penetration data for the cans in 90% steam-10% air with 10 cfm of air flow and 77 cfm of mechanical circulation indicated that heating of the containers in the three planes was relatively uniform in each plane. Cans 2 and 5 located in the center of planes 1 and 2 were the fastest heating containers apparently because they were adjacent to the slot between the two baskets. Cans 4 and 6 in plane 2 were the slowest heating containers and were located in the middle of each basket; they required 17.5 and 16.0 min to reach $\Delta T = 1.8°F$. The time for the slowest vs. the fastest heating container to reach $\Delta T = 3.6°F$ ranged from 12.0 to 15.0 min and to reach $\Delta T = 1.8°F$ 14.0 to 17.5 min (Table 4C2-2).

75% steam-25% air. The heating rates of containers in 75% steam-25% air with 10 cfm of air flow and 77 cfm of mechanical circulation indicated that there were large differences in the heating rates between planes. The heating curves for these containers changed slope at the end of the vent period and at the time of air inlet. The containers in plane 1, cans 1, 2 and 3, did not heat uniformly. Can 1 was the slowest heating, requiring 18.0 min to reach $\Delta T = 3.6°F$ and 21.5 min to reach $\Delta T = 1.8°F$. The containers in plane 2, cans 4, 5 and 6, required the longest time to reach $\Delta T = 3.6$ and $1.8°F$. In this case, can 4 was the slowest heating can in the retort requiring 30.0 min to reach $\Delta T = 1.8°F$ which is large when compared to an average of 16.0 min for the containers in plane 3, the fastest heating cans in the retort. The heating pattern, therefore, indicated that the heating medium flowed around the baskets up to the top plane because the fastest heating zone was at the top of the retort and not through the container stack. The times for the fastest vs. slowest heating container to reach $\Delta T = 3.6°F$ ranged from 13.5 to 20.5 min and to reach $\Delta T = 1.8°F$ 15.0 to 30.0 min (Table 4C2-2).

Heating rate studies of containers in the horizontal retort with 50% of the maximum retort load.

The heating load in the retort is important when considering the time required for the containers to reach processing temperature. The size of the load is important because one of the limiting factors in the rate of come up is the quantity of steam

flow available per unit of time. This quantity is dependent on the size of the steam piping and also the boiler pressure. The following heat penetration tests with a 50% load in the retort were made at the same time as the temperature distribution tests. Temperatures were measured at 9 positions; however, the cans were stacked in 3 levels with each level containing 3 thermocouples in cans and 3 thermocouples beside cans.

Tests were made using 100% steam, 90% steam-10% air and 75% steam-25% air. The steam-air tests were made with a 10 cfm air flow rate.

<u>100% steam</u>. The heating rate data for the containers indicated that the logarithmic curves of temperature vs. time for the containers were straight lines. Heating in all three planes was uniform and the time for all containers to reach $\Delta T=3.6°F$ ranged from 7.5 to 8.5 min and to reach $\Delta T=1.8°F$ 8.5 to 9.5 min (Table 4C2-2).

<u>90% steam-10% air</u>. The heating pattern for the containers in 90% steam-10% air with 10 cfm of air was similar to 100% steam in uniformity. The heating curves for the containers broke at $\Delta T=10$ to 20°F; however, the change in slope for all the curves was very slight, 4.0 min vs. 4.5 min, except for can 8, 4.0 vs. 11.0 min. The curve for can 8 broke at $\Delta T=5°F$. Cans 2 and 5 in planes 1 and 2 which were adjacent to the separation between the two crates were the fastest heating. The time for the slowest vs. the fastest containers to reach $\Delta T=3.6°F$ ranged from 8.0 to 9.5 min and to reach $\Delta T=1.8°F$ 9.0 to 12.0 min (Table 4C2-2).

<u>75% steam-25% air</u>. The heating rate of containers in 75% steam-25% air with 10 cfm of air flow indicated that heating for this condition was not as uniform as the other two tests and that the time for the containers to reach $\Delta T=3.6°F$ and 1.8°F was longer. The fastest heating can was in plane 3. The containers required 11.0 to 11.5 min to reach $\Delta T=3.6°F$ whereas in plane 2, the slowest heating zone, the containers required 12.0 to 14.5 min to reach $\Delta T=3.6°F$. The fastest heating containers in planes 1 and 2 were cans 2 and 5 adjacent to the slot between the baskets. The heating rate curves changed slope at the end of the vent period, and at the time of air inlet. The addition of the air to the retort caused the greatest change in the slope. The time for the slowest vs. the fastest heating container to reach $\Delta T=3.6°F$ ranged from 11.0 to 14.5 min and to reach $\Delta T=1.8°F$ 12.0 to 18.5 min (Table 4C2-2).

Table 4C2-1. Time for each container to reach 1.8 and 3.6°F below processing temperature in a horizontal retort.

				Location						Range
	1	2	3	4	5	6	7	8	9	
100% steam										
$\Delta T=1.8$	13.5	13.0	13.5	13.0	13.5	13.5	12.5	12.5	12.5	12.5-13.5
$\Delta T=3.6$	12.0	12.0	12.0	12.0	12.0	12.0	11.5	11.5	11.0	11.0-12.0
90% steam-10% air										
10 cfm										
$\Delta T=1.8$	15.0	14.0	13.0	15.5	15.0	15.0	13.0	13.0	14.0	13.0-15.0
$\Delta T=3.6$	12.5	12.0	11.5	13.0	12.5	13.0	11.0	11.0	10.5	11.0-13.0
15 cfm										
$\Delta T=1.8$	17.0	15.0	14.0	16.0	16.0	16.0	12.0	13.0	13.5	12.0-17.0
$\Delta T=3.6$	14.0	13.0	12.0	13.5	13.5	14.0	11.0	11.5	12.0	11.0-14.0
20 cfm										
$\Delta T=1.8$	15.5	14.0	12.5	16.5	14.0	14.5	12.0	12.5	13.0	12.0-16.5
$\Delta T=3.6$	14.0	12.0	11.0	13.5	11.0	11.0	11.0	11.0	11.0	11.0-14.0
30 cfm										
$\Delta T=1.8$	16.5	16.0	14.5	16.5	17.5	16.0	14.5	16.0	17.0	14.5-17.5
$\Delta T=3.6$	13.0	12.5	11.5	13.5	13.5	13.0	11.5	13.0	12.5	11.5-13.5
75% steam-25% air										
10 cfm										
$\Delta T=1.8$	22.0	16.0	15.0	31.0	21.0	27.0	12.5	14.0	17.0	12.5-31.0
$\Delta T=3.6$	17.5	13.0	12.5	22.0	16.0	23.5	11.0	11.5	13.5	11.0-23.5
20 cfm										
$\Delta T=1.8$	24.0	19.5	16.0	25.0	21.0	29.0	13.0	14.0	16.0	13.0-29.0
$\Delta T=3.6$	16.5	14.0	14.0	18.0	15.5	24.0	11.5	12.0	13.0	11.5-24.0
30 cfm										
$\Delta T=1.8$	22.0	18.0	13.5	24.0	20.0	27.0	14.0	14.5	17.0	13.5-27.0
$\Delta T=3.6$	16.5	13.0	12.0	18.0	16.0	22.0	12.0	12.5	14.0	12.0-18.0
240°F water cook										
10 cfm										
$\Delta T=1.8$	24.0	26.5	26.0	27.0	29.0	26.0	26.0	27.0	28.0	24.0-29.0
$\Delta T=3.6$	23.5	26.0	25.0	25.5	27.5	25.5	25.0	26.0	26.0	23.5-27.5
20 cfm										
$\Delta T=1.8$	22.5	26.0	24.5	25.0	27.5	25.0	23.5	26.0	25.0	22.5-27.5
$\Delta T=3.6$	22.0	25.0	23.5	24.0	26.0	24.0	24.0	25.0	23.5	22.0-26.0
30 cfm										
$\Delta T=1.8$	20.0	22.5	21.0	22.0	25.0	22.0	20.0	24.0	22.5	20.0-25.0
$\Delta T=3.6$	19.5	21.0	20.0	21.0	22.5	21.0	19.5	22.0	21.0	19.5-22.5

Table 4C2-2. Time for each container to reach 1.8 and 3.6°F below processing temperature in a horizontal retort. Two modifications.

| | 1/2 load in retort | | | | | | Full load with recirculation of 77 cfm | | | |
| | 100% steam | | 90% steam-10% air 10 cfm | | 75% steam-25% air 10 cfm | | 90% steam-10% air 10 cfm | | 75% steam-25% air 20 cfm | |
	$\Delta T=1.8$	$\Delta T=3.6$	$\Delta T=1.8$	$\Delta T=3.6$	$\Delta T=1.8$	$\Delta T=3.6$	$\Delta T=1.8$	$\Delta T=3.6$	$\Delta T=1.8$	$\Delta T=3.6$
1	9.0	8.0	11.0	9.0	15.0	12.0	15.0	13.5	21.5	18.0
2	9.0	8.0	9.5	8.5	14.0	11.0	15.0	12.5	20.5	16.5
3	9.5	8.0	10.0	9.0	14.0	12.5	14.0	13.0	17.5	15.0
4	9.5	8.5	11.0	9.5	18.5	14.5	17.5	15.0	30.0	20.5
5	9.0	8.0	10.0	8.5	14.5	12.0	14.5	12.0	22.0	16.5
6	9.0	8.0	10.0	9.0	18.5	14.5	16.0	14.0	22.5	17.5
7	9.0	8.0	11.0	9.5	12.0	11.0	14.0	12.5	15.0	13.5
8	9.0	8.0	12.0	8.5	13.0	11.5	15.0	13.0	16.5	14.5
9	8.5	7.5	9.0	8.0	12.5	11.0	14.0	12.5	16.0	13.5
Range	8.5-9.5	7.5-8.5	9.0-12.0	8.0-9.5	12.0-18.5	11.0-14.5	14.0-17.5	12.0-15.0	15.0-30.0	13.5-20.5

4D. Discussion of the Results of the Horizontal Retort Tests

100% Steam and Steam-Air Mixtures

The results of the horizontal retort tests using 100% steam support our previous find-
ings that 100% steam has the greatest temperature uniformity and produces the smallest
and most uniform container f-values of any of the heating media studied.

Effect of air.

In comparing the three air flow rates it was observed that the addition of air:
resulted in a temperature drop at the time of air inlet; increased the time required
for the retort to reach an equilibrium processing temperature; and increased the
average f-value of the containers of water in the retort.

The addition of air to the retort caused a temperature drop at some of the points in
the retort. The magnitude of this temperature drop was a function of the concentra-
tion of air in the heating mixture and the air flow rate. The higher the percentage
of air in the heating mixture the larger the temperature drop upon air inlet and con-
sequently the longer the time for all the points to reach equilibrium processing
temperature.

The results show that 90% steam-10% air was very similar to 100% steam in rapidity of
come up and uniformity of heating of the containers. The 75% steam-25% air heating
mixtures showed: the largest temperature drop upon air inlet, the largest equili-
bration times, largest temperature differences between points and consequently the
largest differences in heating rate among containers in each process.

The heating rate data could not be evaluated by the normal heat penetration analysis
methods because semi-logarithmic heating curves of the containers showed several
breaks, one at the end of the vent period and another when the air was added. In
the case where there was a drop in temperature at the container location there were
one or more additional breaks in the heating curve or the points showed a non-linear
semi-logarithmic response.

Effect of heating medium velocity.

The temperature distribution tests in the horizontal retort for 90% steam-10% air
with 10, 15, 20 and 30 cfm of air indicated that an increase in air flow rate from
10 to 20 cfm did not significantly change the temperature profile in the retort;
however, the initial temperature drop upon the introduction of air was decreased
slightly and the time for the points in the retort to reach equilibrium processing
temperature was decreased. Increasing the air flow rate from 20 to 30 cfm of air did
not improve the performance of the heating mixture. The heating rate tests showed
that increasing the air flow velocity from 10 to 30 cfm increased the average time
necessary for the containers to reach $\Delta T=3.6$ and $1.8°F$ and also increased the time
between the slowest and fastest heating containers to reach these temperatures. The
smallest range of heating times to reach $\Delta T=3.6$ and $1.8°F$ was observed for the 10
cfm tests. In conclusion, we can say that Increasing the air flow rate from 10 to
30 cfm in 90% steam-10% air in a horizontal retort does not appear to be highly
significant in improving the efficiency of the heating mixtures.

The temperature distribution studies of 75% steam-25% air with 10, 20 and 30 cfm of air
show that the increase In the air flow rate did not improve the temperature uniformity
of the heating medium. The addition of air to the retort caused a temperature drop

in the first two planes in the retort. The magnitude of this temperature drop was similar in all three tests. In the 20 cfm test, point 6 in the second plane was below processing temperature for 12 min during the equilibration phase; however, at the end of this time it approached 240°F. The time for the points in the retort to reach 240±2°F and 240±1°F was decreased by the increase in the air flow rate from 10 to 30 cfm. The temperature difference between points after reaching equilibrium temperature became smaller as the air flow rate was increased. The heating rate of container tests showed that increasing the air flow rate for 75% steam-25% air decreased the range in times for the slowest vs. fastest heating containers to reach ΔT=3.6 and 1.8°F; however, this apparent improvement in the uniformity of heating was not greatly significant since there were still large differences in the heating times among the containers in the retort.

The vertical retort tests with steam-air mixtures indicated the importance of high air flow rates in maintaining flow of the heating medium through the containers and in this manner maintaining uniform heating conditions. The horizontal retort tests showed that processes with low air flow rates, 10 cfm, were not unlike those with 20 and 30 cfm of air flow. Because of the short path of the heating medium in the horizontal retort, the temperature differences throughout the load were small compared to the vertical retort, and more uniform heating was obtained for steam-air processes in the horizontal retort.

Effect of height of container stack.

The effects of the height of the container stack on the efficiency of a steam-air heating medium were evident when the data obtained from the vertical and horizontal retort tests were compared. Due to the size of the steam supply pipe, 1-1/4 vs. 1-1/2 in. and the reduced boiler pressure 90 vs. 120 psig, the time for the first point to reach processing temperature was longer for the horizontal retort than for the vertical retort, 8.0 vs. 4.0 min.

Comparing the results of the vertical retort with cross spreader tests and the horizontal retort tests, both for 90% steam-10% air heating mixtures, we find that even with this difference in retort come-up-time, that: for the three air velocities the temperature drop at air inlet was smaller for the horizontal retort tests; the time for all points to approach 240±2°F and 240±1°F was smaller for the horizontal retort tests; the heating rates of containers were more uniform for the horizontal retort tests, and the time difference between the slowest and fastest heating container to reach ΔT= 3.6 and 1.8°F was smaller for the horizontal retort tests. The 75% steam-25% air heating mixtures exhibited the same differences as the 90% steam-10% air tests. One point which should be noted is that all containers in the horizontal retort tests reached ΔT=3.6 and 1.8°F whereas this was not true in some of the vertical retort tests.

Comparison of the circular spreader tests of 90% steam-10% air for 10, 20 and 30 cfm of air in the vertical retort and the horizontal retort tests show that: the temperature drop at air inlet was smaller for the horizontal retort; the time for all points to reach 240±2°F and 240±1°F, calculated from the time the first point reached processing temperature, was smaller for the horizontal retort; the temperature difference between points once the retort had reached equilibrium was smaller in the horizontal retort; and the heating rates of the containers showed smaller time differences between the fastest and slowest heating containers to reach ΔT=3.6 and 1.8°F in the horizontal retort. The 75% steam-25% air tests with 20 and 30 cfm of air flow showed that: the time for both processes to reach 240±2 and 240±1°F calculated as time after the first point reached processing temperature were similar for both retorts; the magnitude of the temperature drop upon air inlet was greater in the vertical retort

than in the horizontal retort; the heating rate of container data showed that the differences in time to reach $\Delta T=3.6$ and $1.8°F$ are smaller in the horizontal retort; in both cases the high air flow velocity, 30 cfm, showed large temperature drops upon air inlet, took longer to equilibrate and in the circular spreader tests several containers did not reach $\Delta T=1.8°F$ during the process.

From the above comparisons we conclude that there are major differences in the behavior of steam-air mixtures in vertical vs. horizontal retorts. The largest differences were encountered between the vertical retort with the cross spreader and the horizontal retort. The tests in the vertical retort with the circular spreader showed the effect of the flow pattern on the heating medium, but this improved flow pattern in the retort was not sufficient to overcome the effect of stack height. We conclude, that the shorter stack height obtained, when the horizontal retort was used, is a desirable factor in the design of steam-air mixture processes. High air flow rates in the horizontal retorts did not improve the efficiency of the steam-air mixtures; therefore, in a 7 ft long horizontal retort an air flow rate of 10 cfm was sufficient to maintain flow and mixing of the heating medium mixture.

Effect of mechanical circulation on the efficiency of the heating media.

Two steam-air heating media were tested, 90% steam-10% air and 75% steam-25% air, both for 10 cfm of air flow. The rate of mechanical circulation chosen was 77 cfm, the higher air flow rates were not studied because previous tests showed that there was no apparent advantage in using an air flow rate greater than 10 cfm.

The temperature distribution studies for the 90% steam-10% air tests showed that: the temperature drop at air inlet was smaller for the tests with mechanical circulation, and the final temperature reached by all points was similar for both tests. The heat penetration data showed approximately the same heating pattern for both cases. There was no apparent advantage in using the gas pump to circulate the steam-air mixture for 90% steam-10% air mixtures with 10 cfm of air.

The 75% steam-25% air tests with 10 cfm of air flow and mechanical circulation of 77 cfm showed that in the temperature distribution tests the heating mixture being circulated by the gas pump had larger temperature differences throughout the equilibration phase of the test, but required approximately the same time to equilibrate as the test without mechanical circulation. The heating rates of containers showed that in both cases there were large heating rate differences among containers and that the magnitude of the differences was similar. In both cases the fastest heating cans were located in the top plane of the retort and the slowest heating cans in the center of the stack in plane 2. The data obtained for both of these tests indicated that mechanical circulation of 75% steam-25% air with an air flow rate of 10 cfm did not improve the general effectiveness of this heating medium. The 75% steam-25% air is not considered to be a suitable heating medium for obtaining uniform heating of containers in a commercial horizontal retort system.

Effects of load size on the steam and steam-air heating media.

The come-up-time of the retort was decreased substantially when the product load was reduced 50%. The amount of available heat per container per unit time was greater, therefore heating of the containers was quite rapid. Since the container load was small, the height of the stack was also small, 3 rows of cans vs. 6 rows for the fully loaded retort, and the differences in the heating rates among containers were quite small. There were no measurable temperature differences among points once the retort

reached processing temperature. Three heating media were studied under the 50% load condition, 100% steam, 90% steam-10% air, and 75% steam-25% air with 10 cfm of air flow. The results of the temperature distribution tests showed that the temperature profiles were not widely different from those of the tests with the maximum load considering, of course, the fact that the retort came up to temperature much faster in the tests with 50% of the load. The temperature drop when the air was introduced into the retort was approximately the same in the retort with the 50% load as in the fully loaded retort for the corresponding heating medium. The heat penetration data also showed that due to the fact that the retort reached temperature faster the time required of the containers to reach $\Delta T=3.6$ and $1.8°F$ was also correspondingly smaller for each process. The heat penetration data showed that there were some differences between 100% steam and 90% steam-10% air; however, they were very small. The 75% steam-25% air heating media showed significant differences in the rate of heating of containers throughout the stack. The evaluation of the effect of the load on the performance of a steam-air heating medium suggested that: for flexible package processing 90% steam-10% air was quite similar to 100% steam; that 75% steam-25% air, even at low product loads, showed significant heating rate differences between containers and was at best a poor second to 100% steam and 90% steam-10% air.

Discussion of the Water Process in the Horizontal Retort.

The temperature profiles of the water processes show that: the time required for the
first point in the retort to reach processing temperature decreased with an increase in
the air flow rate from 10 to 30 cfm; the time required for all points to reach $240\pm1°F$
decreased with an increase in the air flow rate; and the magnitude of the temperature
fluctuations, at the beginning of the equilibration phase of the process, were in-
creased by increasing the air flow rate. The heating rate data for the water cook
tests showed that increasing the air flow rate to the retort decreased the time for
the fastest vs. the slowest containers to reach $\Delta T=3.6$ and $1.8°F$; the magnitude of the
range, however, remained approximately the same, about 4 and 5 min, respectively.

We observed in the vertical retort tests that the air flow rate was important in im-
proving the rate of mixing of the water and consequently, in decreasing the time of
come up, but we also observed that this was not the only variable. The air and steam
coming out of the spreader produce motion of the water, and the larger the volume of
air and steam the greater the water flow rate; however, the direction of this flow is
also important. Using the results from the vertical spreader tests we can speculate
that a spreader system which will direct the flow of the heating medium in the hori-
zontal retort will improve the performance of the water process. The present spreader
system directs the flow upwards, but as soon as the gas leaves the spreader and hits
the bottom of the baskets it is deflected and the flow of the water is randomly distributed
throughout the bottom area. A more satisfactory approach would be to have two pipes
running along each side of the basket, at the height of the basket supporting rails,
which will introduce the air and steam along the circumference of the retort so that
the flow of the water is up the side and down through the containers. This arrangement,
we feel, is not only desirable for water but also for steam-air processes. This mod-
ification was not included in our matrix of tests, however, it would be relatively
simple to install and as our data for the vertical spreader suggest, the perform-
ance of a given heating medium will be greatly improved.

In steam-air processes the main heat transfer mechanism is condensation of steam, the
air fraction has a low heat capacity besides the fact that the value of h obtained
for air is very small. If we are processing pouches in horizontally oriented racks the
steam will condense on the surface of the plates leaving the air fraction. The heat
flux due to the air fraction may for our purpose be considered negligible. The water
condensate film poses a resistance to heat transfer and may build up increasing this
resistance. If the racks are placed vertically the condensate will flow down by
gravity and there will be a surface available for continuous condensing of steam. In
steam-air mixtures we must have continuous flow of the heating medium because, as we
have seen before, we cannot allow the formation of cold pockets caused by a stratified
heating mixture. The continuous flow of the heating medium assures that mixing will
take place with the condensed steam being replenished by the supply, and furthermore
the value of h is proportional to the mass rate of flow of the heating mixture.

5. Continuous Pasteurizer

5A. Design of Continuous Pasteurizer Experiments

The continuous pasteurizer experiments were designed to meet the objectives outlined in section 2B. The variables considered were: number of thermocouples in each test, the placement of containers on the conveyor, and the number of tests at each temperature.

The pasteurizer used in these experiments was operated at full load during the tests. The number of thermocouples used per test was directly related to the speed and agility of the operator because of the continuous nature of the pasteurizer operation. The limited time available during each run to put the containers with thermocouples in place on the moving conveyor caused us to decide on four as the number of containers per test. The four cans were placed on the belt in such a manner that we could determine what was occurring along the entire cross section of the conveyor. The cans were placed parallel to one another, equidistant apart on the conveyor.

Water in 303x406 cans was selected as the product in the test containers because of the fast heating properties of water and also because heating rate differences are more easily detected in water, a convection heating product, than in a conduction heating product.

Two types of thermocouples were used in the tests; rod-type thermocouples were placed at the slowest heating zone inside the cans, and plain thermocouples were attached to the top of each container that was fitted with a rod-type thermocouple. This arrangement was used since it was imperative that we compare the ambient container temperature to the heating response of the product in the container. A temperature of 195°F was selected for the tests.

5B. Experimental

Equipment.

The commercial steam-air pasteurizer (Fig. 5B1-1) consisted of a rectangular tunnel about 100 ft. long, 7 ft. wide, and 18 in. deep, open at both ends. A continuous conveyor was located in the bottom extending the entire length of the tunnel. Steam distribution headers were located both above and below the conveyor running lengthwise.   The pasteurizer unit consisted of a number of 10 ft. long sections; the temperature in each section was individually controlled. The temperature control sensing element was located beneath the conveyor belt. Canvas baffles between sections keep the heating medium more or less confined to the section and keep drafts in the building from blowing the steam-air heating medium out of the tunnel.

Temperatures were sensed using the thermocouples constructed at the ends of 24 gage copper constantan wire. The temperatures were measured and recorded using a Honeywell 50 to 350°F 12 point temperature recording potentiometer with a 1 min cycle.

Experimental Procedure.

The steam-air tunnel used in these tests was operated at full capacity at a temperature of 195°F . Four containers were evaluated per test. The procedure followed was to connect the thermocouple wires leading from the containers to a connector box at the end of the potentiometer extension cable. The connector box was located at the inlet or feed end of the pasteurizer. When all thermocouples were connected, the

initial temperature reading was taken, after which time the containers were placed on the moving conveyor. The approximately 80 ft. long thermocouple wires were carefully arranged in a box before the start of each test; as the test progressed, the thermocouple wires were fed into the pasteurizer until the end of the wire was reached, at which time the wire was disconnected from the connector box and allowed to proceed through the pasteurizer tunnel. The wires were sufficiently long that by the time they were disconnected, the containers had passed through the heating zone and were in the tempering or initial cooling zone.
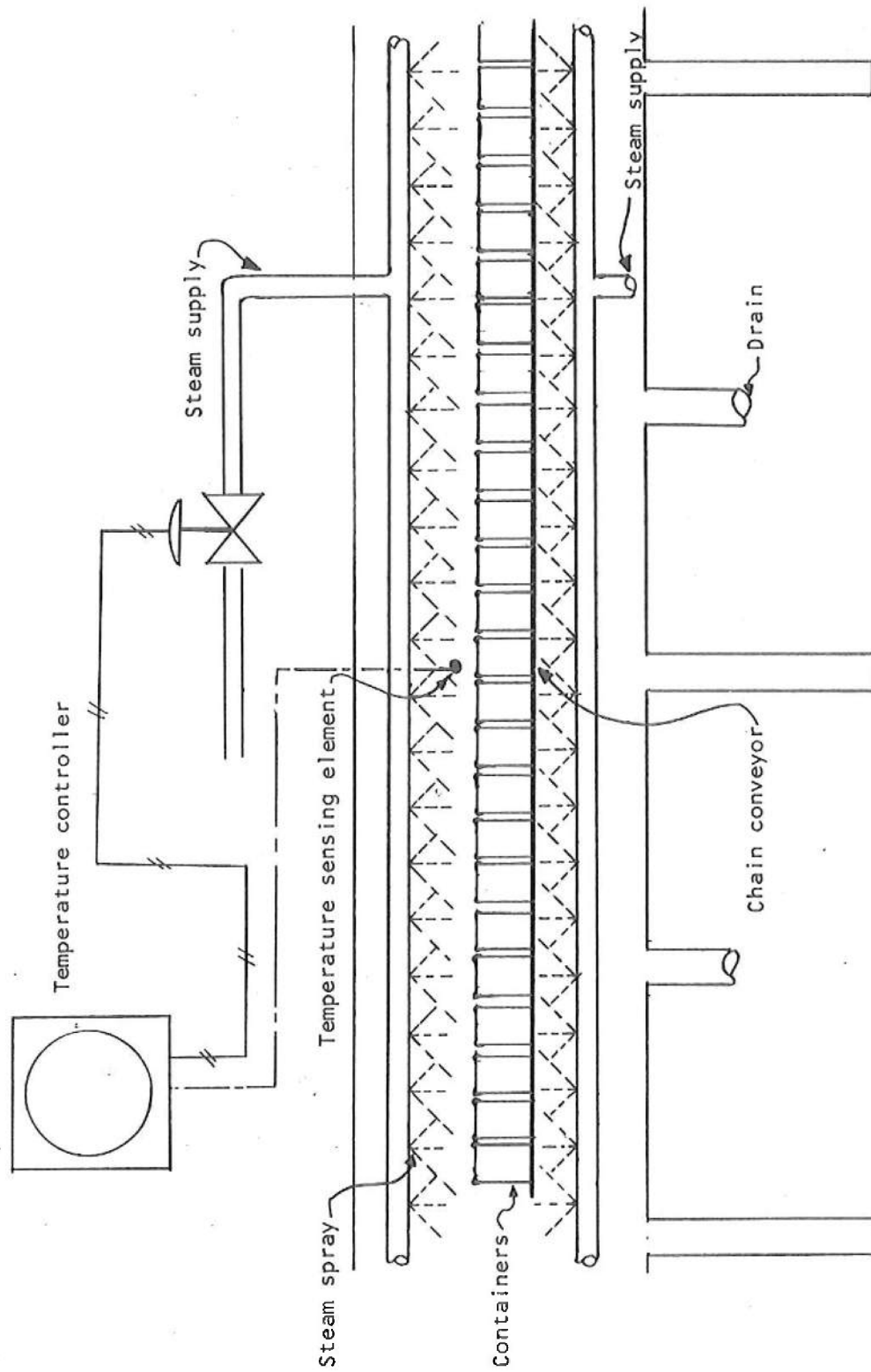
Figure 5B-1. Diagram of a section of a continuous steam-air pasteurizer.

5C. Results

Temperature Distribution Tests in the Continuous Pasteurizer.

The temperature distribution data obtained for the steam-air tunnel were plotted on
an arithmetic grid of temperature vs. time. The temperature distribution chart of
test 1 shown in Figure 5C1-1, indicated that the temperature in the tunnel was
190±5°F 2 min after the containers were placed on the conveyor. The temperature
differences between points were small, 2°F; however, the temperature was not con-
stant throughout the whole process. The temperature of the tunnel reached 198°F 11
min after the containers entered the tunnel and when the containers reached the
tempering zone the average temperature across the pasteurizer dropped to 193°F.

The results of test 2 indicated that the overall temperature of the tunnel was higher
during the heating cycle than in test 1. The average temperature was 196°F for the
first 12 min; however, the heating medium temperature dropped to 190°F during the
tempering period. The difference in temperature between the points during the test
was 2°F (Fig. 5C1-2).

The temperature distribution in test 3, shown in Figure 5C1-3, indicated that there
were large temperature differences between the points during the first 3 min of the
test. Points 1, 2 and 3 dropped 19, 10 and 15°F, respectively. The temperature of
all points was 195±2°F 6 min after the cans were placed on the conveyor. The average
temperature thereafter until the tempering section was reached was 195°F and the
temperature of the tempering zone was 193°F.

The temperature was more uniform in test 4 than for test 3. The temperature pattern
shown in Figure 5C1-4 illustrates that the temperature difference between points for
test 4 did not exceed 3°F during the process and that the average temperature of the
points throughout the heating zone was 196°F dropping to 192°F in the tempering zone.

Figure 501-1. Temperature distribution in a continuous pasteurizer at 195°F, test 1.

Figure 501-2. Temperature distribution in a continuous pasteurizer at 195°F, test 2.

Figure 5C1-3. Temperature distribution in a continuous pasteurizer at 195°F, test 3.

Figure 5C1-4. Temperature distribution in a continuous pasteurizer at 195°F, test 4.
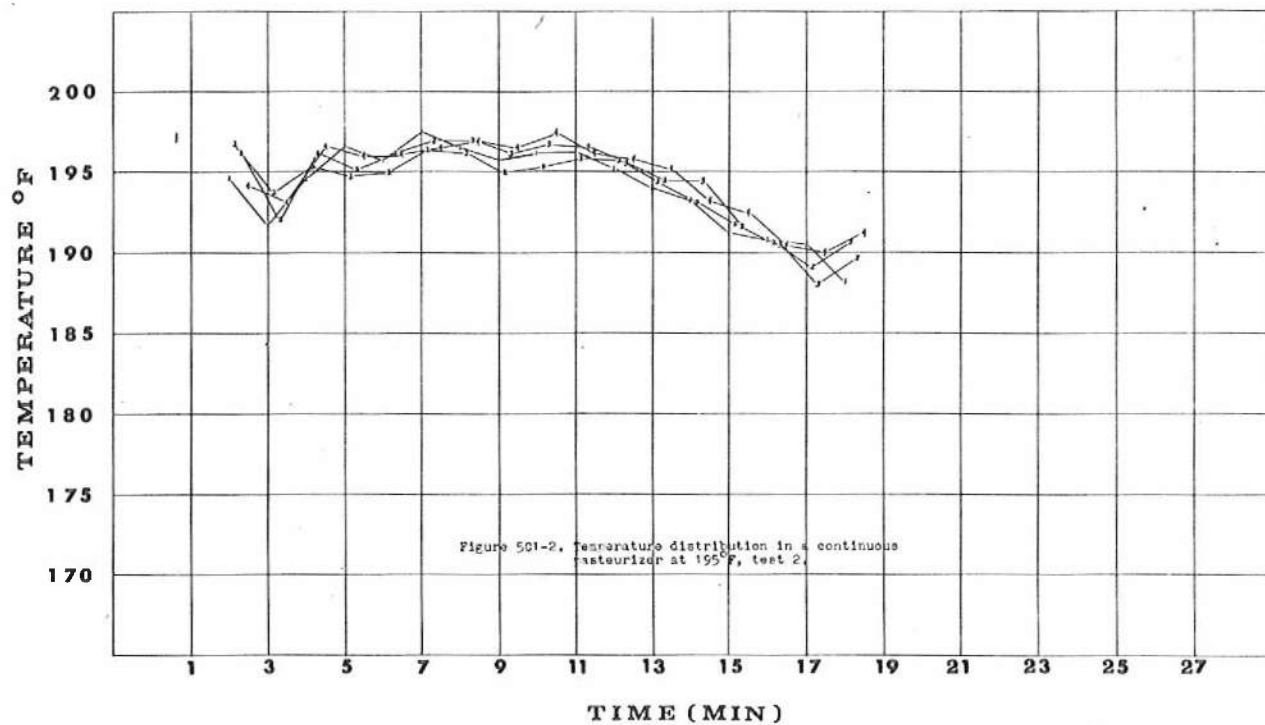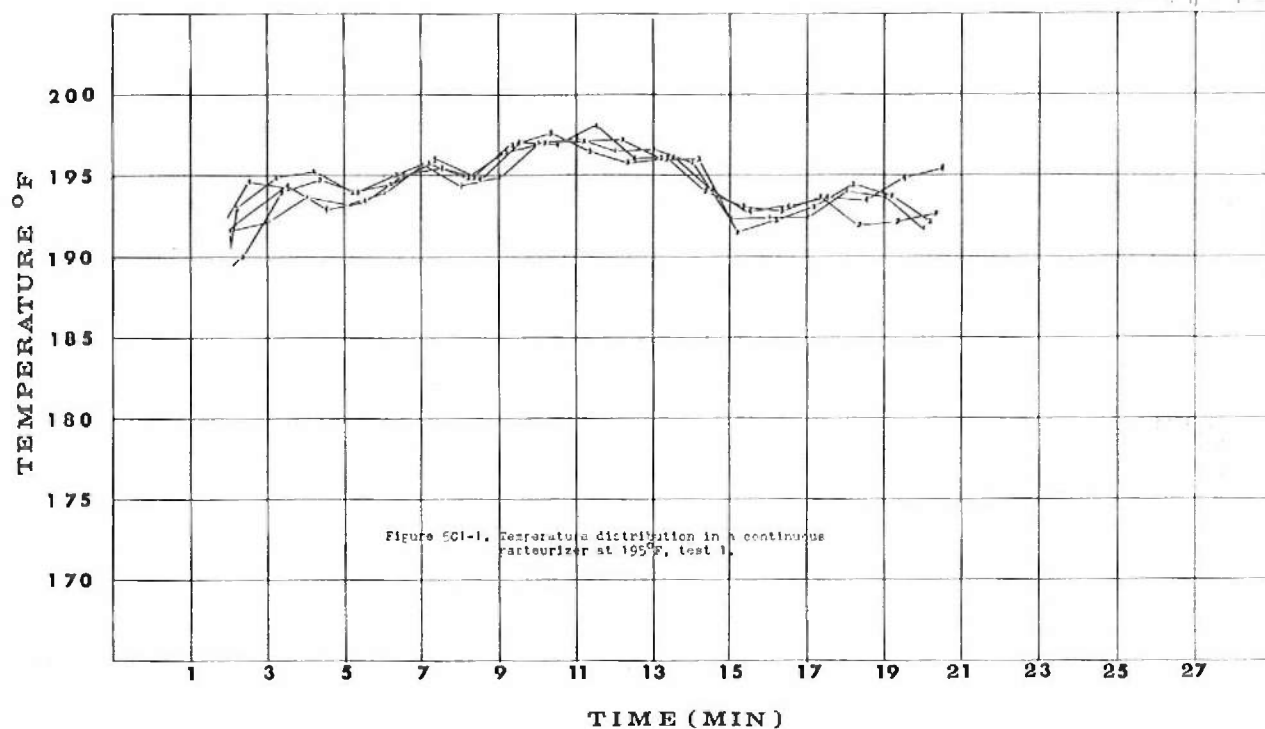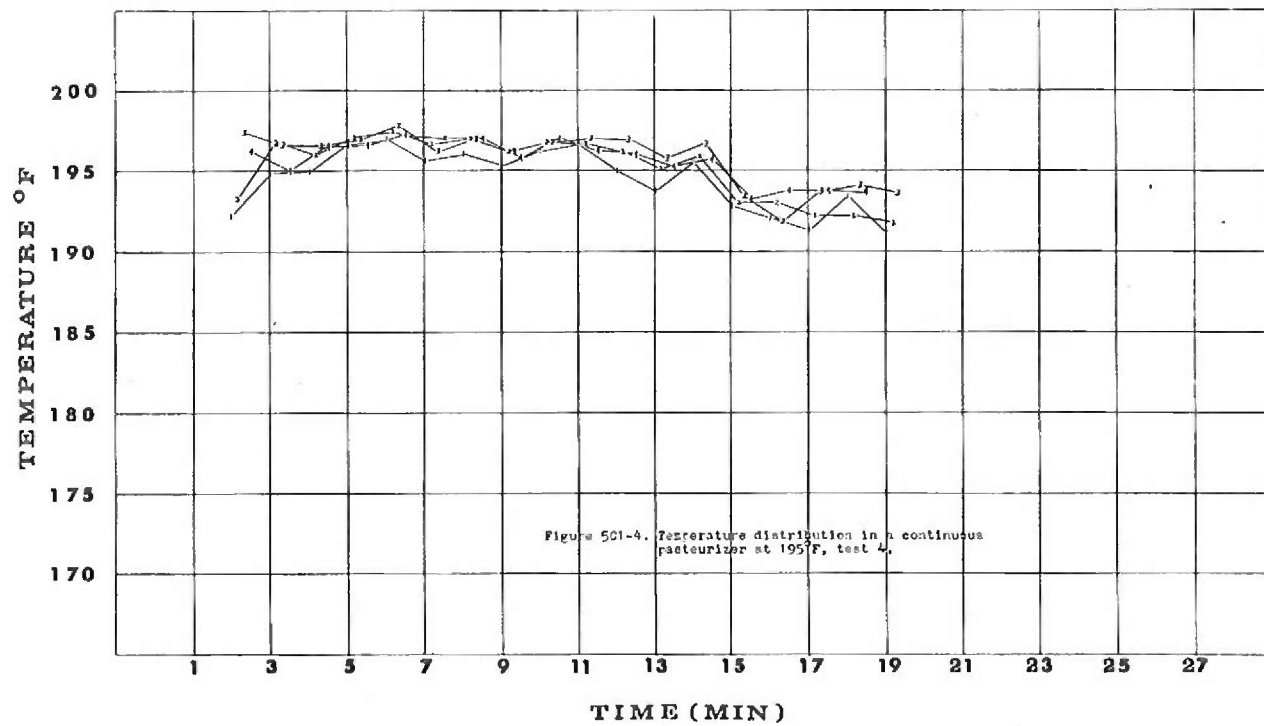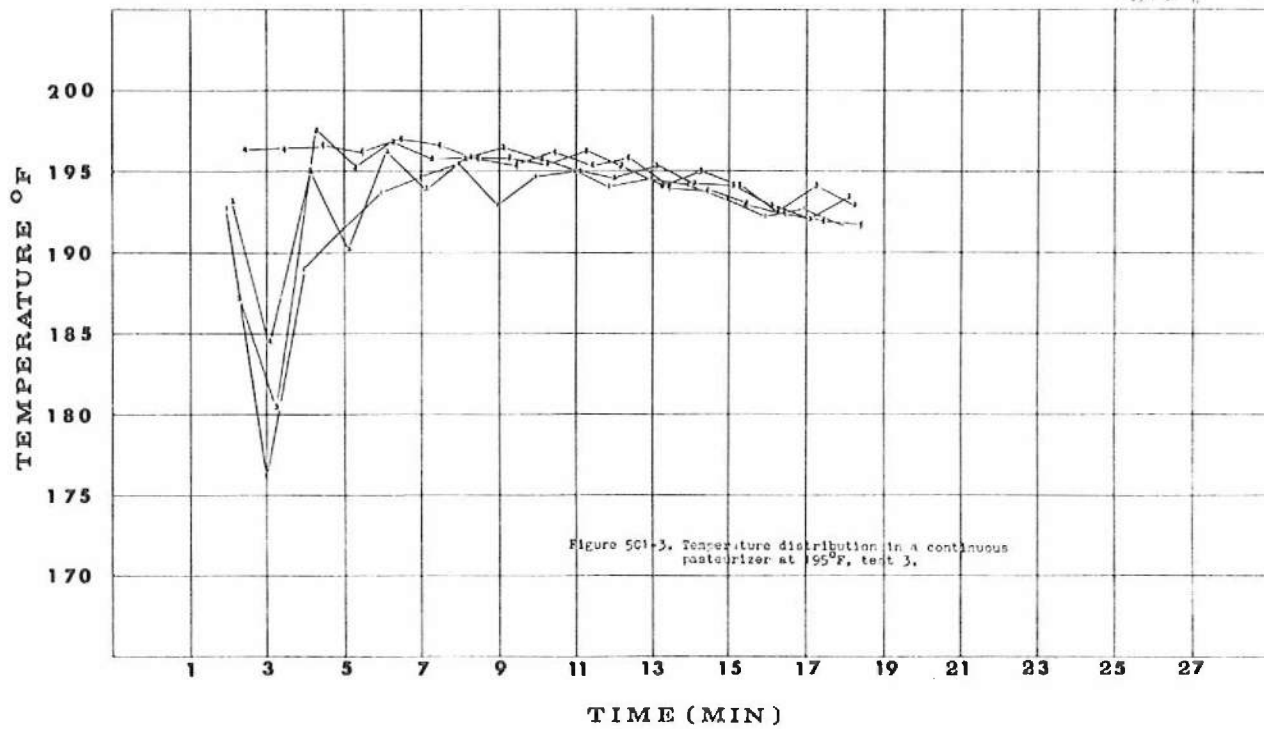
Heating Rates of the Containers in the Continuous Pasteurizer Tests.

The heating rate data of the 303x406 containers of water were plotted on 3-cycle semilogarithmic paper by the method of Ball and Olson (1957). The f-value data obtained from these charts were tabulated and are shown in Table 5C2-1. The study of the heating rate of the containers for the continuous pasteurizer indicated that heating rate differences occurred across the belt; however, the differences were not constant, they were sporadic and not dependent on the location of the container. A measure of the amount of heat received at each point was obtained by determining the highest temperature recorded by each rod-type thermocouple during the process; these data are shown in Table 5C2-2. These results indicate that the lethality received at each point varied substantially.

Table 5C2-1. f(min) values for 303x406 containers of water in the
continuous pasteurizer at 195°F

Container	Test 1	Test 2	Test 3	Test 4
1	6.5	5.0	7.5	5.0
2	6.0	6.0	5.0	5.0
3	6.0	7.5	8.5	6.7
4	7.0	5.0	8.0	5.7

Table 5C2-2. Highest temperature received by each container during the
continuous pasteurizer tests.

Container	Test 1	Test 2	Test 3	Test 4
1	192.0	194.1	191.0	192.7
2	194.4	192.5	193.4	193.8
3	193.1	190.5	189.4	191.2
4	192.9	193.1	190.0	192.5

5D. Discussion of the Results From the Continuous Pasteurizer Tests

The concentration of steam in a steam-air mixture at atmospheric pressure depends on the temperature of the system. The steam concentration in steam-air mixtures at 165, 180 and 195°F is 36.3, 51.1, and 70.6%, respectively. Pflug and Blaisdell (1961) have shown that there is an increase in the heating rate with an increase in the velocity of the heating mixture for containers in steam-air mixtures; however, in a commercial continuous pasteurizer or steam-air tunnel, there is no way to evaluate or control the velocity of the heating mixture. The temperature of the steam at the pipe nozzle is 212°F and as the steam moves out toward the containers the temperature drops as the steam mixes with air. This fact is responsible for some of the difficulties encountered in temperature control. Having separate controls on each 10 ft section helps to reduce the chance of large temperature fluctuations. Due to the particular properties of the system the heat load controls the velocity of the steam-air mixture; a large load produces the highest velocity while a sparsely loaded pasteurizer will have a heating medium flow velocity approaching zero. The temperature distribution studies showed that there were fluctuations of $\pm 3°F$ in the temperature of the tunnel. The fluctuations appeared to be of a random nature both in time of occurrence and regarding location across the conveyor.

The heating rates of the containers in the tunnel indicated that although heating was not uniform for each container in a particular test there was no defined cold zone in the tunnel. The variation in the f-values shown in Table 5C2-1 is from 5.0 to 8.5 min with a mean f-value of 6.3 min. Comparing the data in Table 5C2-1 with the results obtained in Phase I of this project we observe that the f-values in the continuous pasteurizer are large since in steam-air at 190°F the heating curves were broken, the average $f_1 = 3.7$ min and $f_2 = 4$ to 5 min; at 212°F in 100% steam, f = 2.5 min and at 190°F in a water bath f = 4.1 min. Since large f-values mean slower heating we must conclude that the continuous pasteurizer is less efficient as a heating system than the laboratory retort or water bath. These observations should not discourage the use of the steam-air pasteurizer; they only point out the necessity of measuring the heating rates in the unit that will be used for processing.

The position of the temperature controller sensing element was an important design feature; if the container is between the steam jet and the sensing element, the temperature at the sensing element will be substantially lower than the temperature at the container; if the sensing element is between the container and the steam jet, then the temperature at the sensing element will be higher than the temperature at the container.

The continuous pasteurizer is an effective means of processing acid type foods. The configuration and continuous nature of the process is such that flexible packages can be processed very efficiently.

6. <u>Discussion of Heat Processing Non-Agitated Hermetic Containers</u>

6A. General considerations

The sterilization of low-acid food by heating the food in hermetic containers in retorts or autoclaves has been an accepted preservation practice for more than half a century. In spite of the wide use of retorting equipment over a long period of time, published information relating the many variables of the system is practically nonexistant. It is the hope that the discussion below will tie together some of the variables in heat processing.

Three factors are important in retort operation, come-up-time, point-to-point temperature variation in the retort and temperature cycling with time at a given point. The objectives of all systems are: a minimum come-up-time, zero point-to-point temperature difference and zero temperature cycle. The retort performance in the final analysis is determined by the interaction of the many elements that make up the system. However, certain elements exert a greater effect on specific variables, for example: the steam supply system which includes the design of the piping system, control valve size and boiler or line pressure primarily determine the come-up-time of the retort; the retort geometry, loading pattern, spreader design, vent size and location and type of heating media are the variables that influence point-to-point temperature variation, and the control system which includes the control valves determines the temperature cycle.

In the heat processing of food the goal is uniform and reproducible heating conditions. The rate of heating of the package is in itself not critical because the heat process design takes into account the package heating rate; a variation in the rate of heating in different parts of the retort is a problem; when this occurs the heat process must be designed for the heating rate conditions of the containers located in the slowest heating zone.

The Steam Supply System

The still or batch retort is filled and closed, then heating begins. The rate of peak steam consumption for a standard 3-crate vertical or horizontal retort of similar volume will vary from 2500 to 7000 pounds of steam per hour for 1 to 2-inch steam inlets with steam at 100 psi. This peak demand exists only during the come-up-time, when the retort has reached operating temperature the steam demand rate decreases to 100 to 175 pounds per hour (Bock, 1965). The length of the retort come-up-time varies inversely with the rate of steam flow to the retort; the rate of steam flow is a function of the difference in pressure between the steam source and the retort and the flow resistance which is a function of pipe size and length--fitting size and equivalent length. The come-up-time of the retort can be decreased by increasing boiler or line pressure and by increasing the size of the steam lines and associated fittings. For most food products it is important to bring the retort up to process temperature as rapidly as possible because the z-value of quality factors is larger than the z-value of microbial destruction; therefore, a long come-up-time will produce a relatively greater effect on quality than on microbial destruction.

Retort Temperature and Pressure Control

The importance of the control system in overall retort performance cannot be overstressed; a retort system will not operate properly with inadequate controls. The general purpose retort control system requires both a temperature and pressure control device for primary retort control as well as a temperature control for the venting system. Air-operated control systems have been used in the past and are generally used today; the controller produces a modulated air output that is used directly to operate diaphragm control valves. Although the general control system is

the same throughout the industry, the specific aspects of the system vary widely. The major variation among control systems is in the use of on-off controllers and valves vs. the use of proportioning controllers and valves. The names of the systems indicate their mode of operation, the on-off system is a two position type control where the valve is either open or closed whereas the proportioning controller when used with properly sized valves modulates flow so steam supply equals steam demand.

The response time of a control system can be a factor in determining the quality of control. The response time of a pressure controller is very small (for practical purposes near zero) therefore an on-off pressure control system may give relatively little over-peaking compared to an on-off temperature control system using a filled-thermal type sensing element. A temperature control system utilizing a thermocouple sensing element has a very rapid response--similar to a pressure measuring system.

The effect of the control valves and piping on retort operation is often overlooked. Large diameter piping and valves are necessary for rapid come-up of the retort and rapid cooling. Since it is desirable for the heating up of the retort and subsequent cooling to be carried out at a maximum rate, the steam and water control valves should not substantially impede flow.

The retort process cycle consists of a come-up, hold and cool. For good temperature control it must be possible to have high steam flow during come-up for rapid come up to temperature followed by modulated low steam-flow during the process. It may be approaching the impossible to expect a single steam control valve to be large enough to provide high flow during come-up and low flow for uniform temperatures during the cook period. A single large proportioning type valve will undoubtedly do a better job than an on-off control valve. The combination of a large, for example, 1-1/2 or 2-inch on-off steam valve, relay operated, plus a 3/4-inch proportioning type valve in parallel operated by a proportioning controller may be the solution to the problem of having both come-up and process control at a total cost that may be below that of a proportioning system utilizing a single large proportioning type valve.

The sophistication warranted in a retort control system will depend on the food product processed. The heat process is designed for the slowest heating zone in the retort. When there is considerable variation in the rate of heating in different parts of the retort, the product in the rapid heating zone will receive a greater lethality than the product in the slowest heating zone. The difference in lethality of the different zones of the retort will vary depending upon the thermal properties of the product; for example, in a 303 x 406 can of liquid-type food--the F_{TI} probably could vary by as much as 5 min. The difference in quality probably would. not be noticeable in a conduction heating food product in a 303 x 406 or larger can; however, a measurable difference in quality may be produced among the several zones of a retort in a rapidly heating, heat sensitive liquid food product.

Steam Distribution in the Retort

The steam distribution pipe in the retort is called a steam spreader. While it is basically just the steam inlet it is designed to perform a second function, that of influencing the flow pattern in the retort. The retort steam spreader is an extension of the steam line, with perforations equaling 1-1/2 times the area of the inlet pipe, Townsend et al. (1956). The spreader for a short horizontal retort is a single straight pipe extending along the entire length of the bottom of the retort with the perforations at the top of the pipe (NCA Bull 26L, 1962). Several types of

spreaders are used in vertical retorts. The simple cross spreader is most widely used and consists of four stub pipes radiating out from a pipe cross; the pipe is the same size as the steam line and each pipe has perforations on only one side. The four arms of the cross are arranged with the holes opposing one another thus forming alternate live and dead quadrants. This arrangement supposedly gives the steam a swirling motion facilitating the purging of the air from the retort.

In this project a circular spreader has been developed and evaluated. We believe that the cross spreader may be satisfactory for 100% steam processes but that a circular or fish-tail nozzle type spreader should be used in steam-air and water cooks in vertical retorts.

At this point in the discussion of steam spreaders we wish to recognize (1) there is a definite heating medium flow pattern in the retort; (2) the steam spreader plays an important role in the flow pattern; (3) the nature of the flow pattern is intimately related to the heating medium used; (4) the temperature produced density difference forces that are responsible for natural convection are very important in heating medium flow in the retort; (5) the final flow pattern will be the resultant of all the flow forces.

6B.   Heat Processing Containers of Food Products in 100% Steam

In the real food processing world, 100% steam does not exist; however, it is possible to obtain a heating medium that is 99.9+% water vapor and it is this commercial heating medium that we will consider.   The steam we are discussing is wet steam meaning that vapor and water droplets are in equilibrium, the percentage of water in the mixture will range from near zero up to about 10 percent.   Under wet steam conditions temperature and pressure are precisely related; if the temperature of the vapor is known, the pressure can be determined and conversely if the pressure is known the temperature can be determined from the "steam tables".   If the retort contains 100% steam, the pressure is 29.7 psia (about 15 psig) and when equilibrium is established the temperature of the steam in all parts of the retort will be 250°F.   If the temperature of the steam in one part of the retort is cooled and the pressure maintained at 29.7 psia or about 15 psig, the steam in the low temperature area will condense to water, the water drip or fall to the bottom of the retort and the volume previously occupied by this steam will be filled by steam from the supply.   The process of condensation and replacement takes place on a continuous basis throughout the retort.

During the come-up of the retort the temperature will not be uniform throughout the retort since the steam enters the retort at the bottom and this area must reach temperature before there is any steam to heat the upper areas of the retort.   At the start of the retort heating cycle the retort is filled with air, therefore the steam inlet system - steam spreaders - are, according to the experts, designed to remove air by producing a motion that sweeps out the air during the initial or vent period. The standard vent period is four minutes or until the heating medium in the retort reaches 220°F, whichever is longer.

Control

In the American canning industry, pressure control devices have been used and are still being used for controlling 100% steam processes.   Since temperature control is an absolute necessity in retort operation, variables that affect the temperature-pressure relationship must be eliminated when pressure control is used.   The total pressure in a retort is the sum of the partial pressures of all gases present.   If there is air in a retort, the retort pressure will be the sum of the steam pressure and air pressure.   If a pressure controller is used, and the objective is a 250°F process, the partial pressure of any air present will reduce the steam pressure required to satisfy the controller and thus reduce the control temperature.   All retorts are equipped with an indicating thermometer that is used as a check to insure correct process temperature.   The size of the steam inlet and vent piping are critical to air removal during retort come-up-time; however, when a pressure control is used, the need to remove air is even more critical since the busy cook-room operator hardly has time to stand and watch all the indicating thermometers in a multiple retort installation.   Temperature control rather than pressure control of steam processes is a desirable practice; with automatic temperature control the indicating thermometer assumes its place as a check device rather than the primary basis of control.   The design of the steam spreader is of secondary importance to the control and vent systems in the operation of retorts using 100% steam.

Heat Transfer Rates

When the heating medium is 100% steam the film heat transfer coefficient of the food container is large under all conditions; however, it can still vary within certain general limits.   Vapor mass velocity does not affect the film coefficient.   A stack of cans can be approximated by a baffled heat exchanger for which Kern (1950)

states that baffles do not affect the value of the film coefficient, h, of the condensing vapor unless there is an accumulation of condensate. Since condensate will not accumulate in a stack of cans under normal processing conditions we can conclude that an increase in the vapor veloclty passing the side of the can will not affect the value of the heat transfer coefficient. The film heat transfer coefficients for cans in 100% steam as reported by Merrill (1948) for a 312 x 708 can of lead are 620, 780 and 880 BTU/hr ft^2°F at 220, 240 and 250°F, respectively. For film condensation of steam on vertical tubes, Hebbard and Badger (1933) reported values of 680 to 1900 BTU/hr ft^2°F for $\Delta T = $ 5 to 39°F. Othmer (1929) reported values of 2800 BTU/hr ft^2°F for film condensation of steam on a flat plate for a 10°F ΔT. Ball and Olson (1957) report that for dropwise condensation, h ranges from 4000 to 17000 BTU/hr ft^2°F whereas for film type condensation, h ranges from 680 to 6500 BTU/hr ft^2°F. These values cover a wide range of experimental conditions; however, from the literature cited above we can see that for normal operating conditions in a retort the minimum value of the film heat transfer coefficient h for 100% steam is at least 600 BTU/hr ft^2°F.

In a system for processing foods in containers where the h is large enough that the Biot number, hR/k (k is the food product thermal conductivity and R the container characteristic dimension) is greater than 10 (Pflug et al., 1965) which is a fact for 100% steam, the heating rate of the can becomes independent of the film coefficient and is a function only of the thermal properties of the product and the container dimensions.

Steam is without question the simplest and most effective heating medium generally available and should be used whenever possible. Several problems that exist when 100% steam is used are discussed above; however, these problems are minor compared to the problems of heating with water or steam-air mixtures.

6C. Heat Processing Containers of Food In Water

In food processing, the term water-cook implies that the retort Is filled with water, until the containers are covered, that steam is used to heat the water, and that compressed air is added to produce a total pressure in excess of the water vapor pressure corresponding to the processing temperature. The gas space above the water is filled with a steam-air mixture. The ratio of steam and air in the gas space is determined by the processing temperature and the total pressure of the system.

Water processing has developed along with the glass packaging of thermally processed low-acid foods. When retorting food in glass containers, one of the outstanding attributes of water is to protect the glass container from thermal shock, that may occur at the start of heating if steam is used as the heating medium or at the start of cooling If direct cold water cooling is used. Retorting glass containers in water avoids the thermal shock problem because the heat capacity of the water is large in comparison to the heat added by steam or removed by cold water flowing into the retort. This large heat capacity insures that the temperature change of the water surrounding the glass is sufficiently slow that the glass and water temperatures can equalize thereby eliminating the temperature gradient that is responsible for thermal shock. The use of water results in an approximately 50% increase in heating and cooling costs as compared to the use of 100% steam.

Water Circulation

Water temperature variation in a retort can be large. If the temperature throughout the retort is to be uniform, some system of induced flow must be used. The NCA Bul. 30L (1963) recommends a pumping system for horizontal retorts. In vertical retorts, water flow is usually assumed to take place by convection or through the action of the steam and air. In considering water circulation, the question of rate of circulation and mechanism for circulation is still an open area for speculation and study, especially in vertical retorts.

The flow pattern in a retort is important when 100% steam is the heating medium but is very critical in water and steam-air processes. The forces that produce flow act in a vertical plane. When a material is heated and its density decreases there is a buoyant force created; also when a material is cooled and its density is increased, there is a force downward. Therefore, the natural flow during heating is up & for cooling down; to encourage natural flow in the retort steam should be added in the annular area between basket and retort wall where flow is up, with flow down through the stack of cans where heat is flowing from the heating medium to the containers.

The size of the load of containers is about the same in a vertical and in a horizontal retort. Considering that flow takes place in a vertical plane the distance from the heating medium to the product is shorter in the horizontal retort; therefore the flow pattern is more critical in the vertical retort. Natural convection can be used advantageously in the vertical retort because of its geometry. Probably the most Important aspect of steam and air distribution in both steam-air and water cooks is to be sure that the steam and air are added in such a way that they aid natural convection rather than dissipate their kinetic energy in attempting to act in a way opposite to natural convection.

Present recommendations for vertical retorts for processing food in glass containers are to add the steam and air at the bottom of the retort, either through a pipe cross or fish-tail nozzle type spreader. The action of the air and steam are assumed to produce the necessary circulation. The role of air as a mixing agent

In this type of retort operation warrants a close look. The beneficial effect of air as a mixing agent for liquids can only be due to induced flow brought about by the reduced head in a vertical plane containing an air bubble. A directed series of air bubbles certainly will produce a greater reduction in head than a single bubble. Fluid flow will proceed with the difference in head as the driving force; the reduction in head from a stream of directed air bubbles will produce a greater flow than the corresponding flow for an equal number of bubbles randomly distributed.

The use of the cross spreader for releasing air and steam under the crates of containers for a water cook appears at this time to be a questionable practice. The crate and the cans tend to break up the flow pattern of the air and steam as they move toward the top of the retort, dissipating a great deal of the potential flow effect as the upward flow opposes natural convection flow. At the same time the cross spreader may allow the air and 264°F steam (if total pressure is 28 psig) to flow past the product in the bottom crate which may lead to overcooking. In contrast the circular or fish-tail nozzle type spreader discharges the steam and air at the outside of the retort where it can move upward in the annulus between the crate and retort wall producing columns of gas bubbles and inducing rapid water flow up this annular area. This high velocity water will foster steam-water heat exchange which will take place away from the product.

In the water cook where air is added with the steam, each gas bubble as it leaves the spreader will contain both steam and air. As heat is transferred from the bubble to the surrounding water and some of the steam condenses, the size of the bubble will be reduced; when the bubble reaches the top of the retort it will probably only be air. The steam in the bubble when the bubble leaves the spreader will aid in reducing the head in the annular area and consequently will promote the flow or circulation of the water in the retort. As a design basis, it is suggested that the point-to-point temperature variation of the water in the retort be not more than 1°F after the retort reaches processing temperature. If the water temperature throughout the retort is to be uniform to within 1°F, then we must have organized water flow. The flow rate will be related to the container and product. If 303 x 406 cans of water are heated at a rate of 2°F per minute in a retort and the volume of water in the retort is assumed equal to the volume of product in the cans, a flow rate of two retort volumes per minute will be required (assuming that all steam-water heat exchange takes place in the vicinity of the steam inlet which can be logically expected since the retort is operating as 23 psig for a retort temperature of 250°F producing a steam temperature at the steam inlet pipe discharge of about 264°F). A water flow pattern up the side wall of the retort and then down around the containers seems to have advantages. This type of flow will produce a more uniform heat process throughout the retort since this will greatly diminish or prevent steam at temperatures above the processing temperature from coming in contact with containers of food. In a 250°F processing operation, a food container exposed to 260°F steam for a few minutes could end up with an F_o of 15 to 20 min. when the design F_o was 6.0 min. The cold point in the retort when the cylindrical spreader was used was in the bottom basket as contrasted to a cold point in the top basket when the cross type spreader was used.

Air Flow

In both water and steam-air processes the total pressure in the retort is greater than the saturation pressure corresponding to the temperature of the steam; the difference in pressure is due to the pressure of the air that is added with the steam. The air should be added to the retort continuously.

In water processes the air is vital during the come-up-period because it promotes circulation. The recommended air flow rates are somewhat variable. Townsend et al. (1956) and NCA Bul. 36L (1963) recommend 8 to 15 cfm during come-up and 3 cfm for a three-crate - 4 cfm for a four-crate vertical retort after the retort has reached processing temperature. Owens-Illinois Bulletin (1950) states that 15 to 18 cfm of air flow should be used during the come-up period and 4 cfm during the process. As discussed above, the role of air in promoting circulation in water processes is to displace the water with bubbles of air In an area of the retort thus producing a difference in the water head that will result in water flow. The higher air flow rates at the beginning of the process are designed to increase the circulation of the water in the retort during the time that the retort is being brought up to temperature. Theoretically the air flow rate is decreased when the heating medium in the retort has reached temperature, probably to conserve air. A decrease in the rate of air flow to the retort when it reaches process temperature decreases the rate of flow of the heating medium and increases the chance of cold pockets in the retort due to insufficient mixing. To decrease the rate of air flow when the water in the retort reaches the design process temperature is to assume that heating is complete; this is not the case since the temperature of the product lags behind the water.

In our preliminary tests we evaluated several air flow rates and concluded that air flow rates of less than 10 cfm should not be used. We found that increasing the air flow rate from 10 to 20 cfm shortened the come-up-time drastically; increasing the air flow rate from 20 to 30 cfm further reduced the come-up-time for the three-crate vertical retort. As the air flow rate increased the uniformity of temperature increased and the f-value of the product decreased. In our studies we continued the high air flow rates throughout the cook period. We believe that since the containers are absorbing heat during the major portion of the process time, the high air flow rate should be continued to insure continued uniform temperatures throughout the retort.

Heat Transfer Rates

The come-up-time of a retort filled with containers plus water is longer than when only the containers are in the retort; therefore the heating of the container of food in a retort filled with water is slower than heating in steam. When a liquid food product is heated in water, the temperature of the product in the container will follow the water temperature, lagging 20 to 30°F behind the water temperature. Therefore, evaluation of the heating parameters f and j of the food product in the container, a standard practice in thermal process evaluation, is not very meaningful. If f-values must be formed they should be measured only for the period when the retort is at process temperature. The evaluation and design of thermal processes for food products using water cooks should be made using the "general method"; the process itself should include a standardized retort come-up-time, a designed process time, followed by a standardized cool cycle. When cans are heated in water, the surface heat transfer coefficient will be a function of the parameters that affect the velocity of water past the food container. The surface heat transfer coefficients are much lower where there is only natural convection than where forced convection exists. In the case where the velocity of water flow past the can is known or can be approximated, the correlation of McAdams (1954), shown below, may be used for the computation of the surface heat transfer coefficient. Values of the heat transfer coefficient due to natural convection calculated from correlations of McAdams (1954) for a vertical plate 4-1/2 in. high were 103 and 226 BTU/hr ft^2°F for ΔT = 10 and 120°F, respectively. Blaisdell (1963) observed values of 140 and 180 BTU/hr ft^2°F for ΔT = 60 and 120°F for vertical copper and aluminum 300 x 408 cylinders in an unagitated waterbath. These values are much lower than the values for water under forced convection conditions.

In steady state heat transfer the fluid velocity outside tubes may be correlated with the heat transfer coefficient by the following equation (McAdams, 1954):

$$\frac{h_m D_o}{k_f} = b_1 \left[\frac{D_o G}{\mu}\right]^n \left[\frac{c_p \mu}{k}\right]^m_f$$

where:

b_1 = experimental constant (dimensionless)

c_p = specific heat of film, BTU/lb °F

D_o = outside diameter, ft

f = subscript denoting film property

G = mass velocity of fluid, lb/hr (ft^2 of cross section)

h_m = mean surface coefficient of heat transfer, BTU/hr ft^2°F

k = thermal conductivity, BTU/hr ft^2°F/ft

m,n= experimental exponents (dimensionless, they are always positive)

μ = absolute viscosity of film, lb/hr ft

From this relationship we can observe that the values of the surface heat transfer coefficient are proportional to the flow rate of the heating medium past the container. Merrill (1948) lists h-values of 150, 175, 190 and 210 BTU/hr ft^2°F for a 312 x 708 lead cylinder heated from ambient temperature to 150, 190, 220, and 250°F, respectively in an agitated waterbath. Blaisdell (1963) reports values of 254 and 300 BTU/hr ft^2°F for 300 x 406 transducers of copper and aluminum heated from 60°F to 120 and 180°F, respectively. The heat transfer coefficient values obtained in the stack of cans would be smaller than those found for mechanically agitated systems, but larger than those found for natural convection.

In summary, water can be an effective secondary heat transfer medium in retort operation; however, the mere presence of water does not guarantee uniform temperatures throughout the retort. The water plus superimposed air pressure make possible equilibrium steam bubble temperatures corresponding to the saturation temperature of water for the total pressure condition existing in the retort. In all installations there must be adequate open space for vertical flow of the water through the basket or rack containing the packages of food product. It is our opinion that to obtain uniform heat processing conditions throughout the retort, it is necessary to have a positive water circulating system that will insure that all containers are in contact with flowing water and a steam-water heat transfer system that will insure that only water comes in contact with the high temperature steam.

6D. Heat Processing Containers of Food Product in Steam-Air Mixtures

Steam-air mixtures, although in the gaseous state similar to 100% steam when used as a heating medium behave more like water. As was pointed out earlier, 100% steam has the very desirable characteristic of being able to give up a large quantity of heat with very small changes in temperature; however, the heat capacity of both water and steam-air mixtures is very much smaller and whereas steam essentially disappears when it gives up its heat (it condenses to water and runs off) the air portion of the steam-air mixture remains and in water heating all the water remains. Steam-air mixtures are widely used for heating containers of food product in the temperature range of 150 to 212°F where under atmospheric pressure conditions the percent steam in the steam-air mixture will vary with temperature being 36.3% at 165°F, 51.1% at 180°F, 70.6% at 195°F, and 100% at 212°F. It is this apparent satisfactory use of steam-air mixtures that has been at least partially responsible for the present interest in evaluating the performance of steam-air mixtures in retorts.

Characteristics of Steam-air Heating Media

Consideration of steam-air mixtures for a heating medium should take into account the thermal capacity of the steam-air system in comparison with the heat capacity of other heating medium systems. In Table 6D-1 are shown the heat capacities for 60%, 75% and 90% steam-air mixtures at six different temperatures in the range 165 to 250°F. The values in Table 6D-1 are the calculated quantities of heat that can be recovered when the temperature of the steam-air mixture is reduced 1°F under constant pressure. The values in Table 6D-1 become very meaningful when these heat capacity values are compared to the heat capacity values for water and steam shown in Table 6D-2 and Table 6D-3, respectively. Approximately 970 BTU's can be recovered from a pound of dry saturated steam (at 212°F); however, the specific volume varies with pressure. In the retort we are dealing with a heat load per unit volume; therefore, heat capacity based on volume is more meaningful than heat capacity on a weight basis. In Tables 6D-1, 6D-2, and 6D-3, heat capacities are presented in both BTU/lb°F and BTU/ft^3°F. Using the data in Tables 6D-1, 6D-2, and 6D-3, it is possible to compare the heat capacity of water, steam-air mixtures, and 100% steam. The results of this comparison show that while the range of values for water are from 57 to 61, the values for steam-air mixtures are from a low of 0.37 to a high of 1.65 and steam from 14.4 to 68.3 BTU/ft^3°F. The heat capacity values for 100% steam may appear to be low when compared to water; however, as discussed above, this is the heat capacity of a vapor and heat removal from steam results in a change in state and a very large change in volume. The relative heat capacity of steam-air to water at 250°F is roughly in the ratio of 1 to 40 with the water having 40 times the heat capacity of the steam-air mixture. The heat capacity of 100% steam compared to steam-air mixtures at the same temperature ranges from 20 to 40 at 165°F to 40 to 100 at 250°F depending on the percent steam in the steam-air mixture. In utilizing different heating media we can now recognize that in order to have the same temperature difference in a heating system, one using water and the other using a steam-air mixture, it is necessary to circulate on a volume basis, 40 times the volume of steam-air mixture as of water.

Heating Media Circulation

Obviously steam-air mixtures used for retort heating must be circulated in a positive manner similar to water. The flow rate requirements for positive steam-air circulation can be approximated by starting with the water circulation analysis outlined above and then proceeding through in an analysis of the steam-air mixture conditions. The product being heated in the retort is water in 303 x 406 cans, the product weight per can is one pound. As an initial assumption, it was assumed that the mean temperature of the cans of water was increasing at a rate of 2° per minute and there

was an equal amount of fluid surrounding the cans as in the cans (50% void ratio). If the temperature of the water inside the cans is increasing at a rate of 2°F per minute, the water outside the cans will be cooling at the rate of 2° per minute, and in order to have a 1°F temperature difference, a water circulation rate of two water changes per minute is required. Considering a vertical retort 42 in. in diameter and approximately 6 ft. high as far as container stacking is concerned, we end up with a product enclosed volume of approximately 57.7 cu. ft. Since half of the volume will be cans and half will be water and two water changes per minute are required for a 1° ΔT we will actually need a plug flow rate of 57.7 cu. ft. of water per minute. Now let us proceed to go from water to steam-air mixtures. In the attached tables we note that the heat capacity of water at 250°F is 59.0 BTU/ft^3°F, whereas the heat capacity of a 90% steam-air mixture at 250°F is 1.65 BTU/ft^3°F giving a ratio of heat capacity of water to heat capacity of steam-air mixture of 35.7. To obtain a 1° temperature difference in our retort with steam-air mixtures, assuming that the steam-air mixture behaves in the same manner as water, we will need 35.7 x 57.7 for a total of 2060 cfm of steam-air-gas flow. If we consider a 90% steam-air system under equilibrium conditions only 10% of the volume will be filled with air since 90% shall be filled with steam. Therefore, if we circulate 206 cfm we will be circulating the entire air volume or looking at this another way, if we circulate 206 cfm, the maximum temperature difference that we can have throughout the retort is 10°F or 10 times that for the 2060 cfm circulation. Since in a steam-air mixture we have a non-condensable fraction and a condensable fraction, circulation of 206 cfm will certainly produce less than a 10° ΔT when our containers are absorbing heat at a rate equivalent to 2° per minute of average rise of temperature of the water in the cans. When the container heat gain requirement has been reduced to 0.2°F per minute, a flow rate of 206 cfm should maintain a 1° temperature difference throughout the retort and considering the change of volume with temperature that takes place in a steam-air mixture we will actually have slightly less than a 1°F temperature difference throughout the retort.

In considering the above example, it is important to realize the effect of the percentage of steam in the steam-air mixture and the effect of the temperature of the mixture on the overall operation. We can observe in the attached tables that the heat capacity in BTU/ft^3°F decreases from 1.65 for a 90% mixture to 1.11 for a 75% mixture to 0.72 for a 60% mixture at 250°F, or noting the temperature effect for a 90% mixture we see that at 250°F we have a heat capacity of 1.65, at 212°F a heat capacity of 1.10, and at 165°F a heat capacity of 0.53. In Table 6D-4 are tabulated heat capacities and the percent steam in the steam-air mixture for steam-mixtures at 165, 180 and 195°F for atmospheric pressure conditions.

It is important that we point out that temperature differences are going to be determined by the geometry of the system and the relative heat requirement density of the system. For example, in a vertical retort system, if the loading rate is reduced 50%, then the temperature variation for a given flow condition should be reduced by 50%. When a conduction heating product is being heated, the rate of heat absorption of the product will be considerably less and this will promote a more uniform temperature for a given flow condition. The geometry of the system will affect the convection currents inside the retort; as the distance from the farthest most container to the steam inlet jet is reduced, greater convection mixing will take place and temperature gradients will be materially reduced. Those portions of the food industry that have been using steam-air mixtures for a number of years for heating food products in the range of 150 to 200°F have, in general, not bothered with circulation systems since they have been heating the product in a single layer on a moving belt. The complexity of steam-air systems and the fact that they are similar to steam

systems but at the same time perform so much differently undoubtedly has been largely responsible for a lack of understanding of the behavior of the steam-air system.

Pressure Conditions

To process flexible packages, a system is required where the pressure outside the package is greater than the pressure inside the package. The food industry has used water for processing glass containers to reduce the probability of thermal shock on the containers and help keep closures in place. This method may be used with flexible pouches but it is expensive, the water heats slowly, there is danger from vibration damage during a fast come-up and the thin pouch cross section heats rapidly compared with retort come-up. Since there is no thermal shock problem in flexible packages, a gas plus vapor heating system, air plus steam, may offer advantages over the water system.

If steam and air are considered as ideal gases, then the sum of their partial pressures will equal the total pressure $P_t = P_a + P_s$ and if n_t the total number of moles $n_t = n_a + n_s$ then $P_s = n_s/n_t \, P_t$ or $P_s/P_t = n_s/n_t = \alpha$ where the ratio of the partial pressure of air to the total pressure of the system will give α, the fraction of steam in the system.

P_t = Total pressure of the system, psia

P_a = Partial pressure of air, psia

P_s = Partial pressure of steam, psia

n_t = Total number of moles in the mixture

n_a = Moles of air

n_s = Moles of steam

α = Fraction of steam in the system.

In the practical use of steam-air mixtures we are dealing with a vapor at saturation temperature; the partial pressure of the water vapor (steam) in the system is a function of the temperature of the system. For example, if the temperature is 240°F the pressure of the water vapor is 10 psig (24.6 psia); if the total pressure of the system is 15 psig (29.6 psia) the atmosphere will be 83% steam and 17% air.

The control of pressure in the system is therefore quite important in maintaining the concentration of steam in the system equal throughout the process and consequently assuring the integrity of the container. The temperature controller will maintain a constant process temperature; therefore, the partial pressure of steam will be the same throughout the process, but it is up to the pressure controller to maintain the total pressure of the system constant. The pressure in the retort is generally controlled by means of the dump valve. The dump valve is an air operated valve generally 2 in. or more in size, which may be controlled by an on-off or proportional type controller. During a water cook process the pressure in the retort is of the order of 18-23 psig for a 240°F process. In a water process used for heating glass containers, minor pressure fluctuations can be tolerated and an on-off controller may be used, but in the processing of pouches in water pressure variations cause worn or wrinkled pouch exteriors; therefore, a proportional type pressure control and valve is necessary. In processing with steam-air mixtures it is imperative that a proportional controller be used to maintain constant pressure by modulating the dump valve and at the same time there must be continuous gas flow through the system.

Heat Transfer Rates

Studies in Part I of this project found that the f and j values for products heated in water were between the f and j values for 70 and 90% steam-air mixtures. These results indicate that as far as the heating parameters f and j are concerned, steam-air mixtures are satisfactory heating media.

The transfer of heat from steam-air mixtures is quite complicated. If a mixture of a condensable and non-condensable gas is exposed to a surface at a temperature below the dew point of the mixture, condensation will occur. In the case of film condensation, a layer of water forms on the surface with a film of the mixture of the non-condensable gas and vapor next to it. In the gaseous film the concentration of vapor is lower than in the main body of the mixture. McAdams (1954) points out that because of the difference in partial pressure of the vapor between the main body of the mixture and that at the interface of the gas and liquid films, the vapor diffuses from the main body through the gas film to liquify at the interface.

The film heat transfer coefficient in the steam-air system will be a function of the diffusivity of the steam. The diffusivity of a condensing gas diffusing through a non-condensing gas can be calculated using the Gilliland equation in Kern (1950):

$$k_d = 0.0166 \frac{T^{3/2}}{P_T \, (v_A^{1/3} + v_B^{1/3})^2} \, (\frac{1}{M_a} + \frac{1}{M_B})^{1/2}$$

where

k_d = diffusivity, ft^2/hr

P_T = total pressure, atm

v_A, v_B = molecular volumes of diffusing and inert gases

T = absolute temperature, °K

M_A, M_B = molecular weights of the diffusing and inert gases, respectively.

Diffusivity values have been calculated and are tabulated in Table 6D-5 for several temperature and pressure conditions. From Table 6D-5 we observe that at one atmosphere of pressure the diffusivity of the steam increases as the temperature increases from 165 to 195°F, mainly due to the increase in the concentration of steam In the mixture at the higher temperature. The Gilliland equation on the other hand, shows the diffusivity k_d to be inversely proportional to the total pressure of the system and directly proportional to $T^{3/2}$. Comparing 100% steam with a steam-air mixture, the diffusivity of the steam will be less in a steam-air system at the same temperature because the total pressure will be greater than the pressure in the 100% steam system. As the percent air in the mixture, at constant temperature, increases the total pressure will increase. Therefore the diffusivity of the steam at any temperature will vary inversely with the percent air in the steam-air mixture.

Kusak (1958) studied heat transfer from a system containing both a condensing vapor and a non-condensing gas. In his empirical analysis he found that h_a, the film heat transfer coefficient for steady state condensation of vapors from a non-

condensing gas may be correlated using the relationship

$$h_a = a \left[\frac{G}{\mu L} \right]^{1/3} e^{-cM_A}$$

a,c = experimental constants (dimensionless)

e = Napierian base 2.718 . . .

G = mass velocity of fluid lb/hr

h_a = fictitious gas conductance including all conductances between bulk of gas and condenser surface at L ft. from entrance, BTU/hr ft^2 °F

L = length of condenser, ft

M_a = mole fraction air in the gas-vapor steam

μ = absolute viscosity lb/hr ft

In both the forced convection equation and Kusaks (1958) equation we see that the film heat transfer coefficient varies directly with G^n, therefore an increase in the heating medium velocity around the container will increase h. The direction of the flow may also affect the heat transfer coefficient; for example, if the condensate and the heating mixture are flowing counter-currently than the film thickness will be different than if they are both flowing in the same direction. At high heating mixture velocities when the flow is counter-current the condensate film may be held up by the force of the heating mixture moving up; however, in the case where both the heating mixture and the condensate are flowing down, the high velocities of the heating mixture may substantially increase the film coefficient (McAdams, 1954).

We have attempted to show that the heat transfer film coefficient for steam-air mixtures is a function of the heating medium flow rate, temperature, diffusivity, non-condensable gas concentration and direction of gas flow. The heat transfer film coefficient values for steam-air mixtures obtained by Kopelman (1963) using 300 x 408 aluminum and copper cylinders are tabulated in Table 6D6. Values of the heat transfer coefficient calculated from the equation of Kusak (1958) using a Reynolds number of 2100 are tabulated in Table 6D-7. We feel that for containers in a retort these values are conservative.

Table 6D-1. Heat capacity of several steam-air mixtures calculated as the heat given up when the temperature of the mixture is reduced 1°F (values in table are per pound or per cubic foot of the steam-air mixture)

percentage of steam in steam-air mixture

Temperature	60%		75%		90%	
°F	$\frac{BTU}{lb, °F}$	$\frac{BTU}{ft^3 °F}$	$\frac{BTU}{lb. °F}$	$\frac{BTU}{ft^3 °F}$	$\frac{BTU}{lb. °F}$	$\frac{BTU}{ft^3 °F}$
165	15.21	0.366	21.79	0.432	32.26	0.531
180	14.31	0.440	21.84	0.570	30.45	0.677
195	13.79	0.521	20.78	0.694	29.09	0.856
212	13.06	0.607	19.94	0.859	27.61	1.101
240	11.90	0.694	17.80	1.049	24.82	1.479
250	11.56	0.722	17.21	1.115	24.29	1.651

Table 6D-2. Heat capacity of water

Temperature	$\frac{BTU[a]}{lb.°F}$	$\frac{BTU}{ft^3 °F}$
°F		
165	1.001	60.97
180	1.003	60.75
195	1.004	60.51
212	1.001	59.87
240	1.002	57.21
250	1.003	58.98

[a] Handbook of Chemistry and Physics, The Chemical Rubber Co., 1965.

Table 6D-3.   Latent heat capacity of dry saturated steam

Temperature	$\dfrac{BTU}{lb.}$ [a]	$\dfrac{BTU}{ft^3\ °F}$
°F		
165	999.1	14.4
180	990.2	19.7
195	980.9	26.4
212	970.3	36.1
240	952.1	58.3
250	945.3	68.3

[a] Handbook of Chemistry and Physics, The Chemical Rubber Co., 1965.

Table 6D-4.   Heat capacity of steam-air mixture at 165, 180 and 195°F at one atmosphere of pressure

Temperature °F	Percent steam	$\dfrac{BTU}{lb.\ of\ mixture,\ °F}$	$\dfrac{BTU}{ft^3\ of\ mixture,\ °F}$
165	36.3	8.17	0.449
180	51.1	12.21	0.616
195	70.6	19.98	0.900

Table 6D-5.   Diffusivity, k_d, of steam through air.

Temp. °F	Total pressure lb/in^2	% steam	k_d, ft^2/hr
165	14.7	36.3	1.036
180	14.7	51.0	1.073
195	14.7	70.6	1.111
212	16.3	90.0	1.041
212	19.6	75.0	0.866
240	27.4	90.0	0.646
240	33.0	75.0	0.537
250	33.0	90.0	0.559
250	39.6	75.0	0.465

Table 6D-6. Heat transfer film coefficients BTU/hr ft$^{\lambda}$ °F for steam-air
mixtures (Kopelman, 1963)

Velocity ft/sec	165°F (36% steam-63% air)	180°F (51% steam-49% air)	195°F (70.5% steam-29.5% air)
1.5	34	73	129
3.8	44	75	145
5.8	45	78	154

Table 6D-7. Heat transfer film coefficients for steam-air mixtures at
240°F for a Reynolds number of 2100 calculated from the
equation of Kusak (1958)

% air	h, BTU/ft^2 hr °F
10	244
20	175
40	93
60	51

6E. Summary

The performance of the retort processing system depends on the design of the system. the boiler-piping system determines the come-up-time, the control system determines the magnitude of the temperature cycle, and the heating medium circulation pattern the point-to-point temperature variation.

The temperature control system for all media should be of the proportional type to maintain the designed process temperature with minimum fluctuation. For both water and steam-air mixtures the control system must include a proportional pressure control system to operate the dump valve and a rotameter to measure air flow to the retort.

All three heating media, 100% steam, water and steam-air mixtures produce predictable, reproducible results. The three types of heating media are very different in their behavior: 100% steam and steam-air mixutres are in the gaseous state whereas water is a liquid, water and steam-air mixtures have very low heat capacities compared to 100% steam. Circulation requirements for water and steam-air mixtures are considerably more critical than for 100% steam.

Each type of heating medium has its special attributes; 100% steam is the simplest and most effective heating medium to use. Undoubtedly the commercial operator can do more things wrong using 100% steam and not get into trouble than with any other heating medium. Water is probably second as far as being trouble free; the advantages of water is in making possible total pressures greater than the saturation pressure of steam at the particular operating temperature and the prevention of thermal shock when processing glass containers. Disadvantages are in long come-up-times, greater heat requirement and the hazard of stratification. Both water and steam-air require a very sophisticated control system. Steam-air mixtures are used extensively below 212°F and will perform very satisfactorily at 240 and 250°F. It is necessary to provide circulation when using the steam-air mixture. The retort should be brought up to processing temperature using 100% steam. It is recommended that a 90% steam-10% air mixture be used during the period when considerable heat flow to the product takes place. The pressure is almost constant throughout the retort in steam-air processing, an advantage for certain products in flexible packages.

In water processes there must be reliable water flow. If air is used to circulate water, the air flow rate is critical. For vertical retorts we recommend a circular or fish-tail type nozzle spreader; a minimum of 10 cfm must be used; 20 cfm is recommended. The air is added to the steam prior to entering the retort.

The distance from the steam-air inlet or free circulation space to the center of the retort load is critical in steam-air processing. This distance is, of course, related to the heating medium flow. In the steam-air pasteurizer there is little or no problem even when natural convection circulation is used. In the horizontal retort these distances are relatively short; therefore this is little problem as long as there is flow. In 3 or 4 crate vertical retorts (operated under maximum loading conditions) a relatively long period of time is required for the retort to reach equilibrium.

Heating media flow is in a vertical plane; therefore retort baskets and racks must contain adequate openings to allow the heating media to flow vertically through the stack of containers.

The size of the product load in the retort and the heating characteristics of the product have an effect on the overall performance of the retort system.

In the light of the experimental results for the temperature distribution and heating rate tests, we can say that steam-air and water heating media may be used effectively to process shelf stable foods in flexible packages. Our results indicate that the flow of the heating medium and control of the processing system are important criteria in obtaining a uniform and reproducible heat process. We found larger temperature differences at the higher air concentrations; however, the smaller heat loads in processing flexible packages would decrease the come up times as shown in the tests for a half loaded retort. The procedures and equipment modifications stated in the body of the report are recommended since they were found to be most effective in decreasing temperature gradients, come up times and improving the uniformity of the heat process. Since the distance from heating medium inlet to the most remote product for steam-air mixtures has an effect on the come up time, the horizontal retort was found to produce more uniform heating conditions than the vertical retort. For flexible package processing less complications and more uniform processes were obtained using a horizontal retort system. Water cook processes for flexible packages should use a minimum air flow rate of 10 cfm.

The circular spreader system for the vertical retort was found to decrease come up times and temperature gradients. The nature of the flow pattern for the circular spreader system using a water cook suggests that less turbulence and therefore less wear will be caused to the pouches by using this system.

The continuous pasteurizer is an effective system for processing acid food products in flexible packages.

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Nomenclature		Units
a,b,c	experimental constants	dimensionless
C_p	specific heat	BTU/lb °F
D_o	outside diameter	ft
e	Naperian base (2.71828...)	
F_{T_1}	Equivalent number of min at T_1, the processing temperature, z = 18°F	min
f	temperature response parameter; time required for the asymptote of the heating (or cooling) curve to traverse one log cycle which is the time required for a 90% reduction of temperature on the linear portion of the heating (or cooling) curve	min
G	mass flow rate	lb/ft^2 hr
h	surface film coefficient; h_a, fictitious gas conductance including all conductances between bulk of gas and condenser surface at L ft from entrance; h_m, mean surface film coefficient	BTU/hr ft^2 °F
j	lag factor $(T_a-T_1)/(T_o-T_1)$	dimensionless
k	thermal conductivity	BTU/hr ft °F
k_d	mass diffusivity of steam in air	ft^2/hr
L	length of condenser	ft
M_A, M_B	molecular weight of component A and B	lb/lb mole
M_a	mole fraction of air	dimensionless
m,n	experimental exponents	
n_t	total number of moles in mixture; n_a, number of moles of air; n_s, number of moles of steam	
N_{Bi}	Biot number hR/k	dimensionless
P_a	partial pressure of air in mixture; P_s, partial pressure of steam in mixture; P_t, total pressure of system	lb/in^2
R	radius of tube	ft
V_A, V_B	molecular volume of gas A and B	
z	slope of thermal death time curve, for calculation purposes assumed to be 18°F	°F
α	fraction of steam in mixture	
μ	viscosity	lb/hr ft

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    The objective of this study was to evaluate and compare steam, steam-air and water heating media for processing flexible packages and to develop suitable procedures for using these heating media in commercial processing equipment. A multipoint temperature recording device which measured the temperature of the heating medium and in the container at various locations was used to evaluate temperature gradients and heating rates for the vertical and horizontal retort and for the steam-air pasteurizer. The temperature distribution pattern and the rate of heating of water in 303x406 cans were determined for 100% steam, 90% steam-10% air and 75% steam-25% air mixtures, and water in a commercial vertical and horizontal retort and for a steam-air mixture in an atmospheric pasteurizer. Steam- air and water were evaluated at air flow rates in the range of 10-30 cfm. Steam and steam-air were evaluated using natural and mechanical circulation. The performance of the 3 heating media were studied in the vertical retort using both a cross and a circular spreader system. Satisfactory control procedures for processing flexible packages in the 3 heating media were developed for both horizontal and vertical commercial retorts. The horizontal retort was found to be a more effective configuration for processing using steam-air mixtures.

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